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DENSITY OF CELL SAP IN RELATION TO ENVIRONMENTAL CONDITIONS IN THE WASATCH MOUNTAINS OF UTAH [1]

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INTRODUCTION

Observers of plant life in the mountainous regions of the West are familiar with the striking zonation of the vegetation in series of altitudinal belts of distinctive composition. These range from sagebrush deserts or grasslands at the base of the mountains through successive altitudinal forms representing such diverse vegetative aspects as pinon-juniper woodlands, pine forests, aspen stands, Douglas fir, and, on the summits, subalpine spruce-fir forests. Except for the sagebrush and greasewood-shadscale associations, each zone is practically coextensive with a forest type.[2]

The phenomenon of altitudinal zonation is of particular significance to the silviculturist and the range management specialist because of the fact that many of the problems of the growth and regeneration of forests and the development of the range can best be solved through a determination of the soil and climatic requirements of the different species of each zone. The relation of environmental conditions to the development of forest vegetation is thus of profound importance. For example, in designating the kinds and amounts of timber which can be cut from an area without prejudicing the future composition or rendering the forest liable to windthrow, the alert forester is continually making use of his fund of knowledge of the physiological activities and requirements of the various species in his region. In reforestation activities, success depends upon knowing the cause of successful growth and establishment or of partial success or failure of different species in various forest types under varied environmental conditions. Once the problems of growth and regeneration of forests have been solved, the forester should be able to determine readily what species

[1] Received for publication Feb. 28, 1924—issued Nov., 1924. In the following pages authors are cited for the most important and the more recent researches. References are not given for material which is regarded as a matter of common knowledge among scientists. To those who wish more complete citations for the period up to the time of their publication: Ewart's excellent translation of Pfeffer's "Physiology of Plants" (*102*), Livingston's "Rôle of Diffusion and Osmotic Pressure in Plants" (*83*), and Dixon's "Transpiration and the Ascent of Sap in Plants" (*33*) will be found of great service. In order to give the background for the work and to correlate the present work with that of previous workers in the subject, references to the more important literature are given in connection with the topical discussions.

[2] "Forest type" may be defined as a forest of essentially uniform character as regards composition and development due to given physical and biological factors by which it may be differentiated from other forests of unlike composition. It is evident, therefore, that the environmental conditions responsible for a given forest type must have been practically the same throughout the type at the time the forest was started and during its development. A forest type is usually designated by the name of the dominant tree species which determine the leading characteristics of the type.

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will attain the best growth and development on a given aspect at a given elevation. When the effects of climatic or other factors are once definitely known, failures in planting may be largely avoided by a judicious choice of sites [3] and of especially adapted species.

Since reliable quantitative data on the physiological requirements of native forest vegetation are still very meager, investigations were undertaken to determine site characteristics by studies of native plants as indicators. (*72*, *73*.)[4]

The physiological activities of a plant are, of course, a response to (and therefore must be a measure of) the physical factors of the environment. By numerous close observations it ought, therefore, to be possible to ascertain the exact conditions required for optimum growth and development. If this could be done quantitatively, by the employment of native species as indicators, a way might be found to determine with precision the planting sites most suitable for species with known requirements. In the studies which were accordingly undertaken in the Intermountain Region, which is situated mainly in the Great Basin and the Snake River drainage, it was early found that the water relations of the plant and its environment are of paramount importance, especially where semiarid conditions prevail [5] (*76*, *77*). It is very evident that no environmental factors are more significant than the forces with which the soil withholds and the air withdraws water from the plant.

The results of a study of one phase of the water-relations problem are reported in this paper, namely, the relation which the density of the cell sap bears to environmental conditions in the Wasatch Mountains of Utah.[6] The importance of this relationship will be brought out more fully further on. Before taking up the details of the present investigation, however, the mechanism of absorption, diffusion, and osmotic pressure in plants will be considered briefly as the basis for a proper understanding and interpretation of what follows.

RELATION BETWEEN OSMOTIC PHENOMENA AND CELL SAP CONCENTRATION

Because of its restricting cell walls a plant is compelled to depend entirely upon fluid nutriment. The absorption of water and of dissolved substances by the root hairs and young rootlets is practically the only natural method by which the plant can obtain its supply of nutrients from the soil. The passage of water through the organism, however, is not a simple process. In the first place, not all water-soluble substances, as shown by Jost (*69*, *p. 11–23*), are able to enter the cell; secondly, to reach the interior of the cell, the fluid, with its solutes, must penetrate both the cell-wall and the protoplast—the layer of living protoplasm within the cell. The passage of water through the organism is therefore complicated by the presence of substances in solution, and this involves osmosis, or the

[3] "Site" is regarded by foresters as the summation or combined effect of the climatic and edaphic conditions of an area or environment when considered with reference to its forest-producing power; and is practically synonymous with "habitat" as defined by the ecologist. The relation of the living tree to its inert environment embraces the most fundamental of silvical problems. In fact, a great many of the physiological problems of plant life involve to a greater or less extent the relation of the organism to its environment. The plant in relation to its environment must be regarded, therefore, as a physiologically active organism. The existence, limits, and movements of plant communities are controlled by the physical conditions of the environment.

[4] Reference is made by number (italic) to "Literature cited," pp. 900–907.

[5] This is further elaborated in a report by F. S. Baker and C. F. Korstian now in process of preparation, covering climate, soil, and native vegetation of brushlands as indicators of planting sites for western yellow pine in the intermountain region.

[6] Since the sap upon which the determinations were based was extracted by pressure from the tissues a part is doubtless intercellular rather than intracellular in origin. This is probably but a very small fraction of the whole amount, and can introduce no appreciable error in the results.

movement of the solvent through the cell-wall membranes from the weaker to the stronger solution.

The physicochemical laws of diffusion and osmosis, which underlie the water relations of plants, can only be roughly outlined in this paper. For more complete discussions of these laws, relating particularly to selective absorption, diffusion, and osmotic pressure, the reader is referred to the literature cited herewith, and to standard works on physical chemistry and plant physiology. Many investigations have been conducted to determine the influence upon the organism of the medium in which it is grown, but it is only recently that the osmotic pressure of the cell sap has been studied in this connection. Among such researches those of Drabble and Drabble (*37*), Fitting (*40*), Dixon and Atkins (*26–31, 34–36*), Harris, Gortner and Lawrence (*46, 48–50, 52–61*), Iljin, Nazarova and Ostrovskaja (*68*), and Livingston (*86, 87*) should be mentioned.

The foundations of our present knowledge of osmotic phenomena were laid by Pfeffer (*101*) in 1877 and somewhat later were further amplified by Van't Hoff (*67*). LeClerc du Sablon (*79*) and Livingston (*83*) have shown that the permeability of membranes is an essential factor in the physiology of plants and that all of the material exchanges, whether between the cells themselves or between the cells and the external medium (soil in the case of forest trees), are determined by the laws of osmosis.

These laws set forth explicitly that a substance in solution tends to distribute itself uniformly throughout the entire volume of the solvent. In the plant cell no absorption will take place when the concentration of the solution outside is equal to that within the cell vacuole. If the outside solution is the more highly concentrated, water will actually be withdrawn from the vacuole, which will become smaller. An osmotic interchange through the cell walls thus accompanies and complicates the simple movement of water, and though millions of cells may intervene there exists a direct osmotic relation between the topmost leaf of the tallest Sequoia tree and the soil solution at its root tips.

Osmotic pressure can not be measured directly except with great difficulty, but is readily calculable from the amount by which a solute lowers the freezing point or raises the boiling point of the solvent or from the observed vapor tension of a solution. These indirect methods depend upon the general principles that the depression of the freezing point, elevation of the boiling point, decrease of the vapor tension of solutions, and osmotic pressure are all related phenomena and may be obtained one from the other for any given solution.

A review of the above-mentioned researches convinced the writer that an investigation of the osmotic properties of the intra-cellular fluids of forest vegetation on various sites, selected with reference to wide differences in evaporation and the supply of available soil moisture, would throw considerable light upon the basic physiological problems of silviculture and forest distribution. Chief among these may be mentioned the relative ability of different species to extract water from the soil, and, to some extent, retard transpiration through increased sap concentration; the relation of sap density to frost resistance; and the rôle of the osmotic pressure of the cell sap in the adaptation of exotic species introduced on dry sites in semiarid regions.

EXPERIMENTAL METHODS[7]

In conducting this investigation it was necessary to consider: (1) the selection of sites, (2) the collection of leaf material, and (3) the technique of determining the density of the cell sap.

[7] The writer desires to express his indebtedness to Doctors Harris and Gortner for further details of technique gained through a short sojourn at their field laboratory and through their subsequent visit to the writer's field laboratory in 1920.

SELECTION OF SITES

If differences in the density of the sap are in any way correlated with site, they will presumably be the more pronounced the more diverse the site conditions. Extremely varied site conditions were available in Big Cottonwood Canyon, southeast of Salt Lake City, Utah. The Cottonwood Nursery of the Forest Service proved a suitable place for the establishment of a properly equipped base from which to carry on the tests. Material was collected all the way from the margins of streams in the sagebrush desert southeast of Salt Lake City to timberline on the summit of the Wasatch Range. A supplemental collection was also made on the Beaver Creek watershed near the western end of the Uinta Mountains in connection with other work. Two winter collections were made on the Taylor Canyon watershed in the Wasatch Mountains east of Ogden, Utah. These were not limited wholly to the most typical portions of the sites which are discussed below, but were made as opportunity offered and subsequently classified with reference to site. The differences between the sites, as shown by the averages in the tables which follow, might at first appear not as large as they should be, but it must be remembered that one site grades imperceptibly into another; and the transition between areas as well as the typical portions of each site should, therefore, furnish their quota of determinations. As a further control on this series of tests another was made on the Ephraim Canyon watershed extending from the alkali flats on the desert west of Ephraim, Utah, to the summit of the Wasatch Plateau, where detailed climatic records have been secured from 1913 to 1922 at three different elevations.[8] Many of the samples for these tests were collected in the immediate vicinity of the climatic stations, thus offering an opportunity for correlating sap density with climatological data.

COLLECTION OF LEAF MATERIAL

The leaves were gathered as quickly as possible, and were packed tightly in thick-walled test tubes of about 100 cc. capacity. Every precaution was taken to prevent contamination. Except when additional material was being put in, the tubes were kept tightly closed with rubber stoppers, to preclude loss of water by evaporation and consequent increase of the sap concentration. When material was collected which was still wet with rain or dew the leaves were at once wiped dry with some clean absorbent substance. Before placing the test tubes in the freezing mixture the possibility of contamination was further precluded by capping them with oiled paper held firmly by a strong rubber band. As soon as possible after collection the tubes were placed in a slushy mixture of finely chopped ice and salt, where a temperature of −15 °to −17° C. was maintained. They were later thawed out for the extraction of the sap. Although any suitable receptacle would serve for the freezing mixture, a double-walled water-tight wooden freezing box holding three to four dozen test tubes at a time proved the most satisfactory and efficient equipment for the purpose. Each of the two compartments of the freezing box was provided with a false top which had 18 to 24 holes in it for holding the tubes firmly with their upper ends just above the freezing mixture. The box was covered with a lid which projected down over the sides for about 4 inches. With this type of portable freezing box it was possible to make two-day trips by automobile to remote points and return to the field laboratory with the samples still frozen.

[8] The writer is under particular obligation to Dr. A. W. Sampson, formerly plant ecologist, and H. E. Malmsten, grazing examiner, Great Basin Grazing Experiment Station, who aided very materially in the conduct of the control tests through actual participation in the work, and who have kindly placed summaries of the climatological records at the writer's disposal in advance of their publication in a forthcoming bulletin of this department. Inasmuch as the detailed records are soon to be published by these investigators, the writer has made use of the summaries only, the most of which are shown graphically in figure 5.

TECHNIQUE OF DETERMINATION OF DENSITY OF SAP

The importance of freezing the samples preliminary to extraction of the sap has been fully discussed by Dixon and Atkins (*29*), by Gortner and Harris (*41*), and by Gortner, Lawrence, and Harris (*42*). These studies indicate that this preliminary freezing is essential to increase the permeability of the tissues which yield a more representative sample of the solutes from the smaller as well as from the larger vacuoles. Sap from unfrozen tissues has in all cases resulted in lower concentrations than that from frozen tissue, because of the less complete extractions of the former.

Sap density determinations were made by means of the standard freezing-point depression method used by Cavara (*16*) as early as 1902–1905, later by Dixon and Atkins (*29*), and further developed by Harris, Gortner, and Lawrence (*41*, *42*, *46*, *47*), whereby the osmotic pressure of the sap is calculated from the observed depression of the freezing point. Freezing points were determined by means of the classical Beckmann thermometric method (*6*), which has been widely used in chemistry and biology. The thermometer was read to thousandths of degrees and the results were then expressed in freezing point lowering in degrees C. ($\triangle$) and in atmospheres of osmotic pressure (P), after corrections for undercooling were made by using the formula suggested by Harris and Gortner, as follows:

$\triangle = \triangle' - 0.0125\ \mu\triangle$, in which $\triangle$=the true depression of the freezing point, $\triangle'$=the observed depression of the freezing point, μ=the amount of undercooling in degrees C., and a constant (0.0125) experimentally determined, according to the tables calculated by Harris and Gortner. As a part of the laboratory routine it was necessary to determine the freezing point of double distilled water at the beginning and the end of each day's work. Through the adoption of the simplified technique it became possible to make 50 freezing point determinations in one day, all of which were made by the writer.

On several occasions during the course of these investigations the importance was forcibly brought out of exercising extreme precautions in the collecting and freezing of the samples and the extraction of the sap. Otherwise there can be no assurance that the results obtained will be dependable. Evaporation, especially, must be most carefully watched. A striking example of this is afforded in the case of *Orthocarpus tolmiei*. Specimens of this species collected in an opening in the spruce-fir forest in Big Cottonwood Canyon on September 9, 1920, at an elevation of 8,850 feet and treated in the regular manner showed a freezing point depression of the sap of 1.76° C. or an osmotic pressure of 21.2 atmospheres. In marked contrast, the sap of leaves collected from the same plants at the same time but allowed to lie in the shade exposed to the air for 12 hours depressed the freezing point 2.67° (32.0 atmospheres). This difference was caused largely by the drying out of the leaves. With the water supply cut off and the evaporation of moisture from the stomata continuing, a material concentration of the remaining sap is the obvious result.

Another striking example occurred in connection with two collections of conifers in the spruce-fir type of Ephraim Canyon on July 18 and 22. Both lots were collected and frozen in accordance with the prescribed methods, except that one lot on each date was allowed to stand subjected to hot summer temperatures on the laboratory table for six hours after it had been taken from the freezing mixture but before being taken out of the freezing tubes, while the sap of the other lot was extracted and tested immediately after the leaves had thawed out. The results of this comparison are given in Table I.

TABLE I.—*Effect on sap density of exposure to room temperature*

Species, aspect, and collection date	Depression of freezing point in degrees C.		Osmotic pressure in atmospheres	
	Normal treatment	Left standing 6 hours at room temperature	Normal treatment	Left standing 6 hours at room temperature
Picea engelmanni				
Northern aspect:				
July 18	1.37	1.62	16.5	19.5
July 22	1.17	2.01	14.1	24.2
Southern aspect:				
July 18	1.16	2.38	14.0	28.6
July 22	1.15	1.74	13.8	20.9
Abies lasiocarpa				
Northern aspect, July 22	0.78	1.85	9.4	22.2
Southern aspect:				
July 18	1.36	1.57	16.4	18.9
July 22	0.98	1.66	11.8	20.0
Pinus flexilis				
Southern aspect:				
July 18	1.20	1.92	14.4	23.1
July 22	1.14	1.95	13.7	23.4

It is obvious that the higher concentration in the sap from the tubes which were allowed to stand for 6 hours on the laboratory table was not due to evaporation, since the stoppers had not even been removed after the samples were collected.

The fact that the sap which was expressed from these leaves showed a darker color and had a very unusual odor, slightly rancid and somewhat alcoholic, strongly suggests that oxidation and enzymic action had already set in and that the sap density had thereby been materially changed. These results also suggest the grave danger of using any method of extracting the sap which provides for soaking the leaves in warm water, as this treatment creates conditions which are very conducive to enzymic activity.

When the leaf tissues were thoroughly frozen the tubes were removed from the freezing mixture, washed under a warm water tap to remove salt from the surface and by thawing the tissues quickly to enable a more complete plasmolysis. The tubes were carefully wiped on the outside and around the mouth to remove any remaining salt which may have adhered. The tissues were then removed from the tube and folded in a small square of very heavy muslin which had been previously boiled in two changes of distilled water and carefully dried. The sap was then extracted by thorough and complete pressing in a press specially designed for this purpose.[9] Several different types of presses were employed but most of them failed to exert the pressure required to extract sap from many of the plants growing on the semiarid sites and from the conifers having a mucilaginous sap. The press which finally proved fully satisfactory consisted of a heavily tinned press bowl turned from a 4-inch piece of shaft steel, having a convex surface rising from the inside of the bottom. A plunger made of similar material hollowed out at the end was, by means of the screw in a heavy pipe vise, forced down on the tissue lying between the convex surface of the bowl and the concave surface of the plunger.

The screw was turned down slightly every few minutes to maintain a constant oozing of the sap from the tissue. The tissue was frequently rearranged and

[9] The writer is under particular obligation to Dr. J. Arthur Harris for material assistance and cooperation in this connection.

pressure applied again until as much as possible of the sap was expressed. It was found essential to subject all samples to the same uniform thorough pressing because the last sap obtained from a sample is more concentrated than that which is obtained at first.[10]

ENVIRONMENTAL CONDITIONS

The salient physiographic and geologic features of the central Wasatch region have been well described by Butler and Loughlin (*15*). It is an area of strong relief, extending from an elevation of approximately 5,000 feet at the western base of the range to altitudes of almost 11,500 feet on the highest summits. Many of the slopes are steep and include areas of bare, polished rock. The canyons are U-shaped, the branch canyons being of the "hanging" type and the heads of canyons have the basin or cirque form characteristic of recent glaciation. The important rocks of the region consist of quartz diorite, Cambrian limestone, quartzite and shale which decompose into sandy to gravelly loam or silt loam soils.

The topography of the Wasatch Plateau in the vicinity of Ephraim Canyon is much less rugged than that farther north, due mainly to the fact that the sedimentary sandstones and limestones interbedded with geological clay comprise the greater part of the geological formations. The top of the mountain range is often quite flat and a mile or more in width. The soil is, for the most part, a heavy, highly calcareous clay loam or clay.

The salient vegetational features of the main Rocky Mountain region have been very well described by a number of writers, among whom may be mentioned Bates (*3*, *4*), Pearson (*99*), Ramaley (*104*, *105*), Robbins (*108*), Rydberg (*110*), and particularly Sampson (*113*, *114*), who has studied extensively the ecological relations of the vegetation of the Wasatch Mountains. There are, however, some major vegetational differences between the Wasatch Mountains and the central and southern Rocky Mountains. Pinon pine (*Pinus edulis*) drops out of the pinon-juniper type in north central Utah, leaving Utah juniper (*Juniperus utahensis*) the dominant species of the type. Western yellow pine (*Pinus ponderosa scopulorum*) is found very infrequently in the northern part of the Wasatch Range occurring either upon the limited areas of sandy or gravelly soils or near streams where soil moisture conditions are exceptionally good. In Big Cottonwood Canyon western yellow pine occurs naturally on only one site—a gravelly talus slope having a steep southern aspect.

Another striking contrast between the Wasatch Mountains and the Rockies lies in the greater abundance of aspen (*Populus tremuloides*) in the Utah aspen-fir type, where it frequently forms pure stands on old burns. This temporary type of aspen may be considered a retrogression in the succession of forest types due to fire. Lodgepole pine (*Pinus contorta*) is less prominent in Utah, disappearing entirely south of the headwaters of the Provo River on the Uinta National Forest.

Considerable variation in composition is apparent within the same type in different localities, evidently due principally to factors in the environment and to disturbances in the natural succession. For example, a pure stand of Douglas fir, after being burned over, may be followed by a more or less temporary stand of aspen—a retrogression to a sub-climax stage in the developmental succession. However, the aspen will be gradually and eventually wholly supplanted by the Douglas fir. In Taylor Canyon at present there is little aspen on the potential aspen-fir sites, while it is abundant in this type in Big Cottonwood Canyon. Another notable contrast between the forest types on these two watersheds is

[10] This has been reported also by Gortner, Lawrence, and Harris (*49*) and by Knudson and Ginsberg (*71*).

the absence of Engelmann spruce from the higher elevations on the Taylor Canyon watershed. Engelmann spruce is not found on the west slopes of the Wasatch Range immediately overlooking the large valley which was originally the Great Salt Lake Desert. Its absence is probably caused by the exposure of this side of the range to the full sweep of the prevailing southwesterly winds which blow across the desert and cause excessive evaporation both summer and winter. During the winter they also pile the snow in deep drifts on the leeward side, exposing the bare ground on the slopes to the windward and thus favoring winterkilling there.

In the Wasatch Mountains the study covered a range of 5,500 feet, from the bottom of the valley at an elevation of 4,500 feet where the sagebrush (*Artemisia tridentata*) is characteristic, through the juniper, chaparral, and aspen-fir types to the spruce-fir (*Picea engelmanni-Abies lasiocarpa*) type at 10,000 feet above sea level. The Wasatch Plateau series of observations covered a similar range in altitude from the greasewood-shadscale (*Sarcobatus vermiculatus-Atriplex* sp.) type at 5,500 feet, through the sagebrush, pinon-juniper, oakbrush, (*Quercus utahensis*) and aspen-fir to the spruce-fir type at 10,000 feet elevation. Each of the major plant associations is practically identical with definite vegetative types or life zones, such as those proposed by Merriam (*93*). Utah juniper is found from 4,500 to 7,000 feet in the Wasatch Mountains and the Rocky Mountain juniper (*Juniperus scopulorum*) from 6,000 to 8,500 feet (7,500–9,000 feet on the Wasatch Plateau). Douglas fir (*Pseudotsuga taxifolia*) occurs from 5,500 feet on northern aspects to 10,000 feet on southern aspects (7,500–9,000 feet on the Wasatch Plateau), while white fir (*Abies concolor*) is found from 5,500 feet on northern aspects to about 8,500 feet on southern aspects (7,500–9,000 feet on the Wasatch Plateau). Engelmann spruce occurs from 7,000 feet along streams to 10,000 feet, while alpine fir is found from 7,500 feet on northern aspects to 10,500 feet. On the Wasatch Plateau these two species range from about 8,500–11,000 feet. Blue spruce (*Picea parryana*) has a limited natural range extending from 7,000 to 8,000 feet along stream courses in the canyon bottoms (6,500–8,500 feet on the Wasatch Plateau). Limber pine (*Pinus flexilis*) occurs from 7,500 feet on northern aspects to timber line (10,500–11,000 feet). Aspen extends from about 6,800 feet in canyon bottoms up through the Douglas fir and spruce-fir types to an elevation of 10,000 feet. Narrowleaf cottonwood (*Populus angustifolia*) and other broadleaved species are found along stream courses from the lower valleys to about 7,500 feet.

TABLE II.—*Comparison of mean maximum, mean minimum, and mean temperatures by months in degrees F. for Salt Lake City, and Cottonwood Nursery, Utah*[a]

Stations and temperatures	January	February	March	April	May	June	July	August	September	October	November	December	Average, May–October	Annual
Salt Lake City (4,408 feet above sea level; 45 years record):														
Mean maximum	36.6	41.0	50.9	59.9	68.2	79.1	87.9	86.6	76.2	62.9	49.7	39.2	76.8	61.5
Mean minimum	21.7	25.8	32.7	39.9	46.6	55.1	63.2	62.5	52.6	42.1	32.1	25.0	53.7	41.6
Mean	29.2	33.4	41.8	49.9	57.4	67.1	75.6	74.6	64.4	52.5	40.9	32.1	65.2	51.6
Cottonwood Nursery (7,450 feet above sea level):					1916 and 1918	1916 to 1919	1916 to 1920	1915 to 1920	1915 to 1920	1915–17 and 1919–20				
Mean maximum					56.0	72.6	80.6	78.3	67.5	53.1			68.0	
Mean minimum					29.0	37.7	44.3	41.6	36.0	25.9			35.8	
Mean					42.5	55.2	62.4	60.0	51.8	39.5			51.9	

[a] Data furnished by J. Cecil Alter either in manuscript or published form (*1*, *2*).

The usual relation between altitude and temperature holds in a general way in the Wasatch Mountains. Comparisons of temperatures for Salt Lake City and Cottonwood Nursery are shown in Table II. It is impossible from the mean monthly temperatures to form a clear idea of the relative duration of temperatures suitable or unsuitable for plant growth; that is, the temperatures above or below 40° F. Accordingly the average number of hours having temperatures above and below 40° F. and the number of hours of freezing temperature for June to September inclusive at three different elevations on the Ephraim Canyon watershed on the Manti National Forest about 100 miles south of the Big Cottonwood watershed for the period from 1913 to 1922, inclusive, were determined (Table III).

TABLE III.—*Summation of temperatures with reference to elevation on the Ephraim Canyon watershed*

Elevation (feet)	Type	Average number of hours June-September		
		Above 40° F.	Below 40° F.	Of freezing temperature
7,100	Oak brush	2,786	142	39
8,700	Aspen-fir	2,672	256	78
10,000	Spruce-fir	2,499	426	126

Temperature gradients with altitude have been worked out by several investigators for different mountainous regions in the West. Pearson (*99*) finds a mean altitudinal temperature gradient of 3.68° F. for each 1,000 feet from an elevation of 3,300 feet at Kingman in northern Arizona to timber line on the San Francisco Mountains at 11,500 feet. Shreve (*115*) reports a gradient of 4.11° F. in the Santa Catalina Mountains of southern Arizona. Observations on other mountains in the West, according to Hann (*43, p. 243–246*), have resulted in the following gradients: Sierra Nevadas in Placer County, California, 4.12° F.; Pikes Peak, Colorado, 3.46° F. Air temperatures decrease quite uniformly with an increase in altitude, except for local inversions which are occasionally encountered due to air drainage in canyons and mountain valleys.

Precipitation in the Wasatch Mountains increases rapidly with altitude up to and including the aspen-fir type, as shown in Table IV. From this type to the spruce-fir type the increase is less pronounced, but the snowfall in the spruce-fir type on the high mountains is considerably heavier. Although not strictly comparable because the records for these stations do not cover the same period, they are nevertheless significant. They indicate an increase in the annual precipitation of 6.4 inches for each thousand feet. Alter's (*1*) study of the relation between precipitation and altitude, for practically all groups of adjacent stations with simultaneous records, on the western slope of the Wasatch Mountains, shows an increase in precipitation of from 15 inches annually at the lower elevation (4,250 feet) to 33 inches at the higher elevation (8,700 feet), or uniformly 4 inches per year per 1,000 feet. On the eastern slope on the leeward side of the range the precipitation decreases more rapidly with decrease in altitude, being nearly 5.5 inches for each thousand feet for the composite of all stations studied by Alter.

TABLE IV.—*Comparison of mean monthly and annual precipitation in inches for various altitudes in the Wasatch Mountains*[a]

Stations	January	February	March	April	May	June	July	August	September	October	November	December	Average precipitation May to October	Average annual precipitation
Salt Lake City (4,408 feet above sea level): Years of record, 1874–1920	1.35	1.47	2.07	2.01	2.00	0.81	0.52	0.77	0.97	1.54	1.37	1.35	6.61	16.23
Lower Mill Creek (4,959 feet above sea level): Years of record, 1914–1920	2.46	2.18	2.46	2.35	2.38	1.10	0.95	0.58	1.75	2.51	1.77	1.67	9.27	22.16
Cottonwood Nursery (7,450 feet above sea level)[b]	-----	-----	-----	-----	2.52	1.31	1.42	1.60	2.52	3.28	-----	-----	12.65	-----
Silver Lake (8,700 feet above sea level)[c]	5.47	6.41	6.28	4.39	2.56	0.48	1.05	2.03	3.17	3.84	2.93	5.24	13.13	43.85

[a] Data furnished by J. Cecil Alter either in manuscript or published form (*1*, *2*).
[b] Years of record are: May, 1916 and 1918; June, 1914–1919; July–October, 1914–1920.
[c] Years of record are: January and February, 1907 and 1916–1922; March, 1916–1922; April and May, 1916–1921; June, 1909 and 1916–1921; July, 1907, 1908, and 1915–1921; August, 1907, 1909, and 1915–1921; September and October, 1907–1909, and 1915–1921; November and December, 1915–1921.

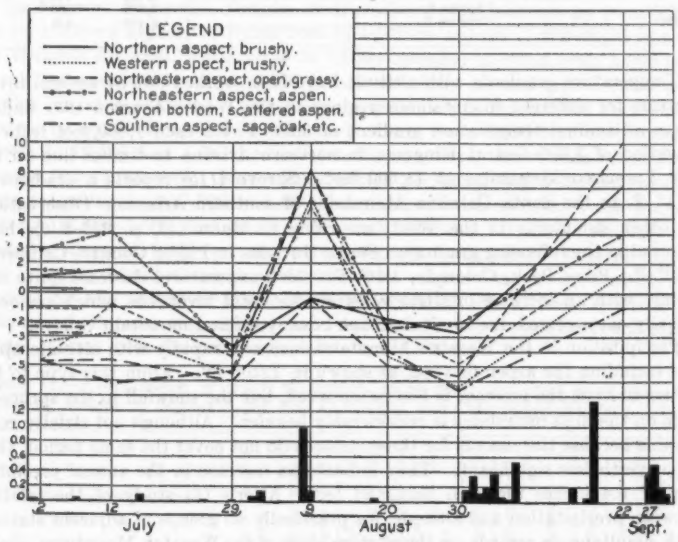


FIG. 1.—March of available soil moisture at depth of 6.12 inches and daily precipitation, Big Cottonwood watershed, central Utah, season of 1919
(Seasonal averages shown by horizontal lines at left of graph)

Very low summer precipitation and marked dryness of the surface soil characterize the Wasatch Mountain sites at low altitudes. At the Cottonwood Nursery June and July, with less than 1.5 inches, have the lowest average monthly precipitation. August has only 1.60 inches. The meagerness of the rainfall is further reflected in the amount of available soil moisture. The changes in soil moisture and in evaporation were recorded in 1919 and 1920 on several typical

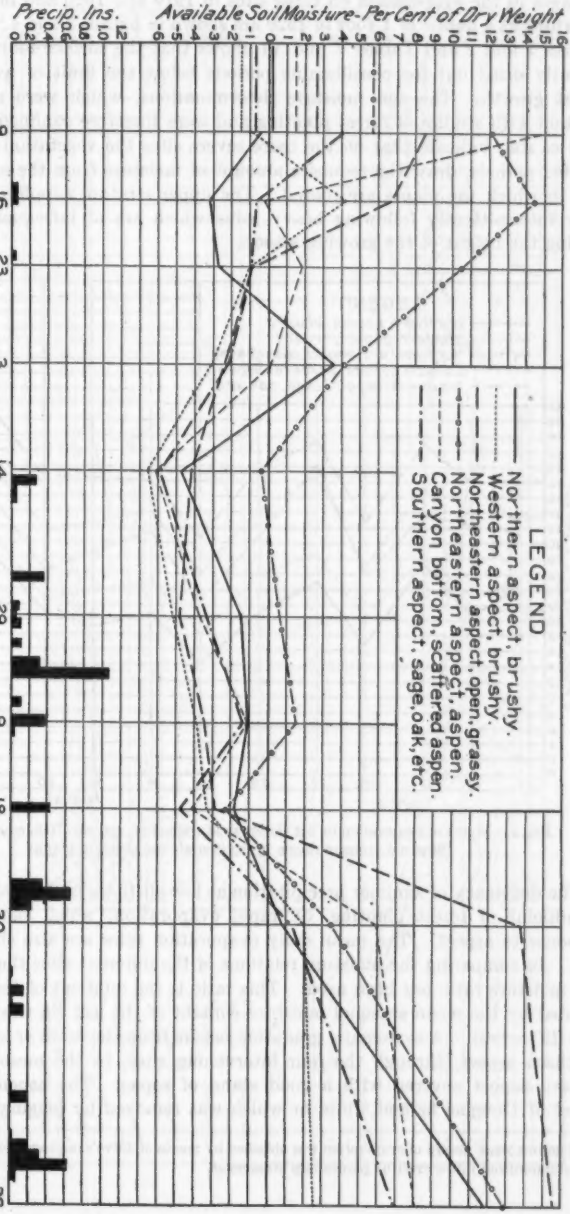


FIG. 2.—March of available soil moisture at depth of 6-12 inches and daily precipitation, Big Cottonwood watershed, central Utah, season of 1920 (Seasonal averages shown by horizontal lines at left of graph)

sites in the aspen-fir zone. The data are presented in figures 1 and 2. The changes in the evaporation on these sites in 1919 and 1920 and in the soil temperature at a depth of 1 foot in 1920 are shown in figures 3 and 4.[11] A study of figures 1 and 2 and Tables V and VI shows that the surface foot of soil is frequently dried out for considerable periods below the limit of availability for plant growth. The soil moisture determinations, which were made in connection with studies of forest planting and were therefore confined to the upper foot of soil, indicate that on the more severe sites the vegetation must, for extended periods, draw the requisite amount of moisture from the lower layers of soil in which the plants are rooted. The upper stratum supplies soil moisture only intermittently following heavy rains which are of infrequent occurrence during the height of the growing season.

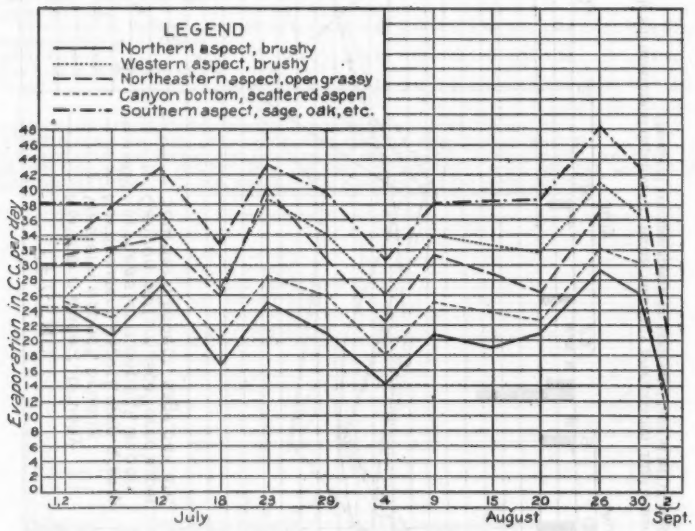


FIG. 3.—March of evaporation in Big Cottonwood watershed, central Utah, season of 1919 (Seasonal averages shown by horizontal lines at left of graph)

The deficiency of summer precipitation at low altitudes is aggravated, from the standpoint of forest planting, by rapid evaporation, which shows a marked response to aspect. The mean daily evaporation rates are also shown for each site. In comparing the moisture relations of the different sites the evaporation-soil moisture ratio has been used. This ratio is the quotient of the evaporation divided by the mean seasonal moisture content of the soil (in this case a depth of 6–12 inches). A systematic gradation occurs from the more or less xerophytic southern aspect, through the four intervening sites, to the mesophytic northeastern aspect covered with a good stand of aspen. The aspen succeeded a forest of Douglas fir and white fir which was removed by logging and fire.

[11] The two years' record of evaporation was obtained by means of Shive's improved form of the Livingston standardized rain-correcting porous cup atmometer.

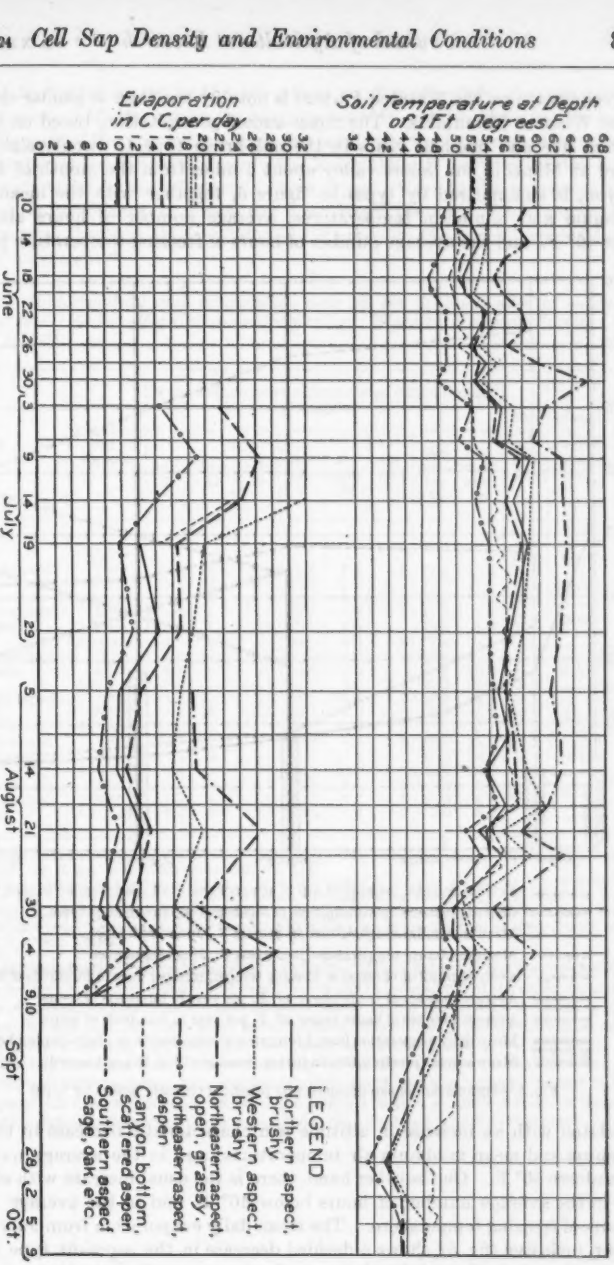
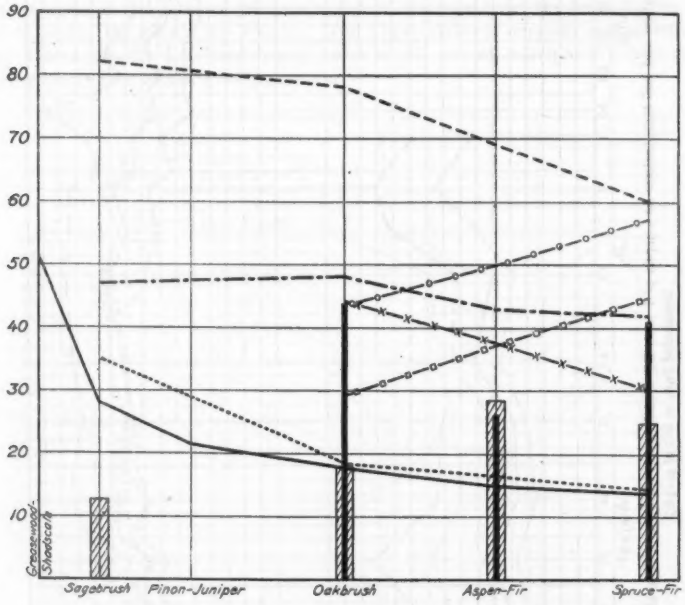


FIG. 4.—March of evaporation and soil temperature at a depth of 1 foot, Big Cottonwood watershed, central Utah, season of 1920. (Seasonal averages shown by horizontal lines at left of graph)

Precipitation on the Wasatch Plateau is notably less than at similar elevations in the Wasatch Mountains. The mean annual precipitation, based on averages of from five and one-half years in the oak-brush type to twenty-eight years' record at Manti in the desert valley about 6 miles from the mouth of Ephraim Canyon, is summarized by types in figure 5, together with the mean annual maximum and minimum temperatures, average number of hours above and below 40° F., and the average number of hours of freezing temperature per year.



Average osmotic pressure of sap in atmospheres of all species tested in each type.
Osmotic pressure in atmospheres of sagebrush sap in different types.
Mean maximum temperatures in degrees F., June–September.
Mean minimum temperatures in degrees F., June–September.
Average number of hours of freezing temperature per year in hundreds of hours.
Average number of hours above 40° F. per year in hundreds of hours.
Average number of hours below 40° F. per year in hundreds of hours.
Mean daily evaporation from Livingston atmometers in cc., July–September, 1916.
Mean annual precipitation in inches (average of 5 to 28 years record).

FIG. 5.—Summation of sap densities and principal climatic factors by types

Associated with an increase in altitude is a characteristic decrease in the mean maximum and mean minimum air temperatures, and in the average number of hours above 40° F. On the other hand, there is the usual increase with elevation both in the average number of hours below 40° F. and in the average number of hours of freezing temperature. The mean daily evaporation from July to September, inclusive (fig. 5), shows a decided decrease in the aspen-fir type as compared with that in the oak-brush type. In the spruce-fir type the evaporation is almost as great as in the oak-brush type, largely because of the fact that the climatological station in this type is situated on an open southern aspect which

is exposed to the full sweep of the prevailing southwest winds, the velocity of which Sampson (*113*) has shown to average notably greater than in the lower types. Because of the prevailingly high temperatures, the longer growing season, and the higher rates of evaporation in the lower types it follows that the mean annual precipitation is less effective in these types. Even in the oak-brush zone the rainfall is insufficient to leach the lime from the soil. This complex of adverse factors, therefore, has a profound influence on the type of vegetation at the lower elevations.[12]

TABLE V.—*Soil moisture and evaporation data on six different sites at elevations of 7,500 to 7,700 feet, Big Cottonwood watershed, Wasatch National Forest, Utah, season of 1919*

Site	Depth of soil sample	Total soil moisture percentages at different dates of sampling								Wilting coefficient[a]	Mean daily evaporation	E.[b]
		July 2	July 12	July 29	August 9	August 20	August 30	September 22	Seasonal average			S. M.
	Inches									*Per cent*	*c. c.*	
Northern aspect, brushy.	0-6	13.2	10.5	5.2	9.8	7.8	7.4	23.4	11.0	13.6		
	6-12	12.4	12.8	7.6	10.9	9.5	8.6	18.5	11.5	11.3	21.29	1.85
	Average..	12.8	11.6	6.4	10.4	8.6	8.0	21.0	11.2	12.4		
Western aspect, Ceanothus-oak.	0-6	4.4	5.0	2.7	19.8	5.8	3.0	11.3	7.4	10.9	33.46	3.80
	6-12	7.5	8.1	5.4	17.3	6.6	4.6	12.2	8.8			
	Average..	6.0	6.6	4.0	18.6	6.2	3.8	11.8	8.1			
Northeastern aspec open, grassy.	0-6	7.9	4.8	3.6	21.0	8.3	5.6	30.4	11.7	17.9		
	6-12	9.8	9.9	8.5	14.0	9.6	8.8	24.6	12.2	14.5	30.07	2.46
	Average..	8.8	7.4	6.0	17.5	9.0	7.2	27.5	12.0	16.2		
Northeastern aspect, aspen.	0-6	14.9	15.1	7.6	16.0	10.4	9.2	19.6	13.3	14.7		
	6-12	15.5	16.7	8.6	20.8	10.2	10.6	16.6	14.1	12.6	(c)	[c] 1.51
	Average..	15.2	15.9	8.1	18.4	10.3	9.9	18.1	13.7	13.6		
Canyon Bottom, scattered aspen.	0-6	10.0	13.0	7.8	24.4	9.2	8.4	19.8	13.2	16.2		
	6-12	8.8	12.7	9.2	19.3	11.2	8.7	16.6	12.4	13.5	24.45	1.97
	Average..	9.4	12.8	8.5	21.8	10.2	8.6	18.2	12.8	14.8		
Southern aspect, sage-Ceanothus-oak-aspen.	0-6	3.0	3.1	4.0	20.4	6.1	2.6	8.4	6.8	12.4	38.27	3.99
	6-12	7.7	6.2	7.0	20.6	8.5	5.8	11.4	9.6			
	Average..	5.4	4.6	5.5	20.5	7.3	4.2	9.9	8.2			

[a] Determined in the Biophysical Laboratory, Bureau of Plant Industry, United States Department of Agriculture by the Briggs and Shantz centrifugal method.

[b] Evaporation divided by the mean seasonal moisture content of the soil at a depth of 6-12 inches.

[c] Atometer was broken by a bear early in the season. In computing the ratio of evaporation to the soil moisture content, the evaporation was considered equal to that on the brushy northern aspect. This is shown to be ultra-conservative by the 1920 records which show the evaporation to be lower on the aspen-covered northeastern aspect.

[12] Studies conducted in the Wasatch Mountains by Sampson (*113*) and Baker and Korstian (unpublished) agree in the main with the more detailed studies of Pearson (*99*) in indicating that the upper limits of the distribution of a species or forest type are determined primarily by low temperature as related to photosynthetic activity and that the lower limits are determined primarily by a deficient moisture supply. Deficient moisture rather than high temperature is regarded as the determinant at the lower levels, since the observations by Baker and Korstian in this region, as well as those of Pearson in the Southwest, indicate that practically all of the species, when adequately supplied with moisture through irrigation or when growing along stream courses, some 1,500 feet below their natural range, are capable of enduring high temperatures far in excess of those to which they are subjected at the lower limits of their natural range.

TABLE VI.—*Soil moisture and evaporation data on six different sites at elevations of 7,500 to 7,700 feet on Big Cottonwood watershed, Wasatch National Forest, Utah, season of 1920*

Site	Depth of soil sample	Total soil moisture at different dates of sampling									
		June 9	June 16	June 23	July 3	July 14	July 29	August 9	August 18	August 30	September 28
	Inches	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Northern aspect, brushy	0-6	9.0	6.0	6.1	5.1	3.6	9.1	14.2	8.8	17.0	21.5
	6-12	10.9	8.1	8.6	15.0	6.6	9.8	10.2	9.5	12.1	23.2
	Average	10.0	7.0	7.4	10.0	5.1	9.4	12.2	9.2	14.6	22.4
Western aspect, Ceanothus-oak	0-6	10.0	11.5	5.7	4.2	4.4	7.9	9.2	9.3	18.0	20.5
	6-12	10.0	15.2	9.9	7.8	4.4	5.7	7.1	7.6	12.9	13.5
	Average	10.0	13.4	7.8	6.0	4.4	6.8	8.2	8.4	15.4	17.0
Northeastern aspect, open, grassy	0-6	20.2	16.6	8.8	9.3	4.8	10.1	16.6	11.0	30.9	35.4
	6-12	23.0	21.2	13.5	12.1	10.3	9.7	11.1	11.7	28.2	30.1
	Average	21.6	18.9	11.2	10.7	7.6	9.9	13.8	11.4	29.6	32.8
Northeastern aspect, aspen	0-6	28.9	23.9	20.8	19.5	10.2	18.6	21.7	9.4	28.1	36.5
	6-12	24.7	27.1	23.1	16.6	12.2	13.2	14.2	10.4	16.2	25.5
	Average	26.8	25.5	22.0	18.0	11.2	15.9	18.0	9.9	22.2	31.0
Canyon bottom, scattered aspen	0-6	13.8	11.3	10.0	7.5	5.5	12.3	18.1	8.5	24.3	23.5
	6-12	27.9	13.3	15.4	13.5	7.3	9.8	12.5	9.4	19.5	21.6
	Average	20.8	12.3	12.7	10.5	6.4	11.0	15.3	9.0	21.9	22.6
Southern aspect, sage-Ceanothus-oak-aspen	0-6	7.4	5.4	6.6	6.9	3.4	11.0	14.5	6.0	15.8	17.2
	6-12	16.4	11.7	11.5	10.2	6.5	9.1	11.1	7.6	13.8	19.4
	Average	11.9	8.6	9.0	8.6	5.0	10.0	12.8	6.8	14.8	18.3

Site	Depth of soil sample	Seasonal average of soil moisture	Wilting coefficient [a]	Mean daily evaporation	$\frac{E}{S.M.}$	$\frac{E}{S.M.}$ mean of 1919 and 1920 [b]
	Inches	*Per cent*	*Per cent*	*Cc.*		
Northern aspect, brushy	0-6	10.0	13.6			
	6-12	11.4	11.3	10.86	0.95	1.40
	Average	10.7	12.4			
Western aspect, Ceanothus-oak	0-6	10.1	} 10.9	18.65	1.98	2.89
	6-12	9.4				
	Average	9.8				
Northeastern aspect, open, grassy	0-6	16.4	17.9			
	6-12	17.1	14.5	15.12	0.88	1.67
	Average	16.8	16.2			
Northeastern aspect, aspen	0-6	21.8	14.7			
	6-12	18.3	12.6	9.96	0.54	1.02
	Average	20.0	13.6			
Canyon bottom, scattered aspen	0-6	13.5	16.2			
	6-12	15.0	13.5	19.13	1.28	1.62
	Average	14.2	14.8			
Southern aspect, sage-Ceanothus-oak-aspen	0-6	9.4	} 12.4	20.90	1.79	2.80
	6-12	11.7				
	Average	10.6				

[a] Determined in the Biophysical Laboratory, Bureau of Plant Industry, United States Department of Agriculture by the Briggs and Shantz centrifugal method.
[b] Evaporation divided by the mean seasonal moisture content of the soil at a depth of 6-12 inches.

SAP-DENSITY DATA

The object of this study was to attempt a correlation of the major vegetational types with the cell-sap density of representative plants. The procedure therefore involved a systematic sampling of each of the well-marked types. In the Ephraim Canyon investigation six such types were recognized: (1) greasewood-shadscale, (2) sagebrush, (3) pinion-juniper, (4) oak brush, (5) aspen-fir, (6) spruce-fir. In the main Wasatch Mountains eight major vegetational types or associations were considered: (1) stream-bank, (2) sagebrush, (3) juniper, (4) western yellow pine, (5) chaparral, (6) lodgepole pine, (7) aspen-fir, (8) spruce-fir. With the exception of the stream-bank association, these types form

a regularly graduated succession from the xerophytic sagebrush to the climax mesophytic spruce-fir type.[11] These types were further divided into sites, differentiated chiefly on the basis of aspect and consequently varying as to moisture supply, rate of evaporation, temperature, and exposure to sunlight. The possible effect which altitude might have upon sap density was also taken into account in selecting some of the sites on which the various species were collected.

In the Central Wasatch Mountains some 500 sap density determinations were made on representative trees, shrubs, and herbs of the above-mentioned types. The samples were collected in Big Cottonwood and Taylor Canyons, lying near Salt Lake City and Ogden, Utah, respectively. In the Ephraim Canyon series of July, 1921, approximately 275 determinations were made of the sap densities of plants on the west slope of the Wasatch Plateau and on the desert in the adjacent San Pete Valley.

TABLE VII.—*Freezing point depressions and osmotic pressures of the sap of trees classified by species, locality, type, situation, altitude, and date of collection*

[Numbers in italics represent averages of two or more determinations]

Species and locality	Type	Situation	Altitude	Date of collection	Depression of freezing point	Osmotic pressure
Juniperus utahensis (Engelm.) Lemm.			*Feet*	*1920–1921*	*Degrees C.*	*Atmospheres*
Big Cottonwood Canyon.	Juniper	Southern aspect	5,000	July 21	*2.19*	*26.3*
Do	do	do	5,000	Sept. 17	*[c]1.32*	*15.9*
Do	do	do	5,000	Dec. 10	*2.31*	*27.8*
Taylor Canyon	do	do	5,200	Jan. 4	2.12	25.5
Do	do	do	5,200	Feb. 28	2.14	25.7
Do	do	do	7,000	do	2.35	28.2
Pinus ponderosa scopulorum Engelm.						
Big Cottonwood Canyon.	Western yellow pine	Southern aspect	6,400	July 21	*1.93*	*23.2*
Do	do	do	6,400	Sept. 22	1.44	17.3
Do	do	do	6,400	Dec. 10	1.38	16.6
Near Park City highway.	Isolated trees	Eastern aspect	6,800	Sept. 17	*1.47*	*17.7*
Beaver Creek	Western yellow pine	Southern aspect	7,000	Sept. 16	1.86	22.4
Do	do	do	7,300	do	1.82	21.9
Do	do	do	7,600	do	1.77	21.3
Big Cottonwood Canyon.	Aspen-fir	Canyon bottom [a]	7,500	July 7	1.57	18.9
Do	do	do	7,500	July 27	*1.35*	*16.2*
Do	do	Southern aspect, under light shade.[a]	7,500	July 19	*1.36*	*16.4*
Do	do	do	7,500	July 27	*1.35*	*16.2*
Do	do	Canyon bottom [a]	7,500	Sept. 20	*1.36*	*16.4*
Do	do	Canyon bottom under snow.	7,500	Dec. 8	*1.17*	*14.1*
Juniperus scopulorum Sarg.						
Big Cottonwood Canyon.	Western yellow pine	Southern aspect	6,400	July 21	*1.41*	*23.9*
Do	Chaparral	do	7,600	July 26	1.60	19.2
Do	Western yellow pine	do	6,400	Sept. 22	0.99	11.9
Do	Chaparral	do	7,600	Sept. 7	0.94	11.3
Do	do	do	7,600	Sept. 10	0.92	11.1
Do	Western yellow pine	do	6,400	Dec. 10	2.41	28.9
Do	Chaparral	do	7,600	Dec. 6	2.17	26.1

[a] Planted, species exotic to this site.
[c] Sample collected after a heavy rain.

[11] These types are not essentially different from the successional formations of Clements (*80, 81*). His two recent monographs constitute a thorough treatment of the purely successional aspects of the type problem. Here the author has brought together his extensive observations on the relations of vegetation to environmental conditions; and has shown that the changes which occur in the character of the vegetation of a given plant association are the result of gradual changes in climate and soil conditions and reactions of the plants upon the environment.

TABLE VII.—*Freezing point depressions and osmotic pressures of the sap of trees classified by species, locality, type, situation, altitude, and date of collection*—Con.

[Numbers in italics represent averages of two or more determinations]

Species and locality	Type	Situation	Altitude	Date of collection	Depression of freezing point	Osmotic pressure
			Feet	*1920–1921*	*Degrees C.*	*Atmospheres*
***Juniperus scopulorum* Sarg.**						
Beaver Creek	Western yellow pine	Southern aspect	7,000	Sept. 16	1.40	16.8
Do	do	do	7,300	do	1.55	18.6
Do	do	do	7,600	do	1.39	16.7
Ogden, Utah		City park [a]	4,350	Jan. 25	2.23	26.8
Taylor Canyon	Aspen-fir	Northern aspect	5,200	Jan. 4	2.20	26.4
Do	Juniper	Southern aspect	6,600	do	2.06	24.8
Do	do	do	7,600	do	2.01	24.2
Do	Aspen-fir	Northern aspect	5,200	Feb. 28	1.75	21.0
Do	Juniper	Southern aspect	8,500	do	2.84	34.1
***Pseudotsuga taxifolia* (Lam.) Britton**						
Big Cottonwood Canyon.	Western yellow pine	Southern aspect	6,400	July 21	*1.74*	*20.9*
Do	Aspen-fir	Canyon bottom	7,400	July 23	*1.16*	*14.0*
Do	do	do	7,400	July 25	1.36	16.4
Do	do	Southern aspect	7,500	July 19	1.62	19.5
Do	do	do	7,500	July 26	1.54	18.5
Do	do	Northern aspect	7,600	July 13	1.62	19.5
Do	do	do	7,700	July 19	*1.70*	*20.4*
Do	Spruce-fir	do	8,500	July 24	1.58	19.0
Do	Western yellow pine	Southern aspect	6,400	Sept. 22	1.41	17.0
Do	Aspen-fir	do	7,500	Sept. 7	1.32	15.9
Do	do	do	7,500	Sept. 10	0.90	10.8
Do	do	do	7,500	Sept. 12	1.15	13.8
Do	do	Northern aspect	7,700	Sept. 7	1.41	17.0
Do	do	do	8,250	Sept. 20	1.04	12.5
Do	Spruce-fir	do	8,500	Sept. 12	1.18	14.2
Do	Aspen-fir	Western aspect	8,500	Sept. 20	*0.98*	*11.8*
Do	do	do	9,600	do	1.07	12.9
Do	do	Southern aspect	10,000	Sept. 9	0.89	10.7
Do	Western yellow pine	do	6,400	Dec. 10	1.32	15.9
Do	Aspen-fir	do	7,500	Dec. 6	1.24	14.9
Do	do	Northern aspect	7,600	Dec. 7	1.32	15.9
Do	do	Western aspect	9,500	do	1.05	12.6
Beaver Creek	do	Northern aspect	7,000	Sept. 17	[c] 0.79	9.5
Do	do	Eastern aspect	7,300	Sept. 16	1.75	21.0
Do	do	do	7,400	do	1.75	21.0
Do	do	do	7,600	do	1.62	19.5
Taylor Canyon	do	Northern aspect	5,200	Jan. 4	0.57	6.9
Do	do	do	7,800	do	0.57	6.9
Do	do	do	5,200	Feb. 28	0.74	8.9
Do	do	do	7,000	do	0.66	8.0
Do	do	do	8,500	do	0.66	8.0
Big Cottonwood Canyon.	do	Canyon bottom [b]	7,400	July 27	*1.59*	*19.1*
Do	do	do	7,400	Sept. 22	*1.50*	*18.0*
Ogden, Utah		City park [a]	4,350	Jan. 25	0.92	11.1
***Abies concolor* (Gord.) Parry**						
Big Cottonwood Canyon.	Aspen-fir	Northern aspect	5,500	July 21	1.66	20.0
Do	Western yellow pine	Southern aspect	6,400	do	*1.96*	*23.6*
Do	Aspen-fir	do	7,500	July 19	*1.30*	*15.6*
Do	do	do	7,500	July 26	1.35	16.2
Do	do	Northern aspect	7,600	July 13	1.71	20.6
Do	do	do	7,700	July 19	*1.52*	*18.3*
Do	Western yellow pine	Southern aspect	6,400	Sept. 22	1.15	13.8
Do	Aspen-fir	do	7,500	Sept. 7	1.32	15.9
Do	do	do	7,500	Sept. 10	0.93	11.2
Do	do	do	7,500	Sept. 12	1.07	12.9
Do	do	Northern aspect	7,700	Sept. 7	1.20	14.4
Do	do	do	8,250	Sept. 20	1.04	12.5
Do	do	Ridge top	8,650	do	1.19	14.3
Do	Western yellow pine	Southern aspect	6,400	Dec. 10	0.83	10.0
Do	Aspen-fir	do	7,500	Dec. 6	1.35	16.2
Do	do	Northern aspect	7,600	Dec. 7	1.28	15.4
Do	do	Ridge top	8,000	do	1.47	17.7

[a] Planted, species exotic to this site.
[b] Planted although native to site.
[c] Sample collected after a heavy rain.

TABLE VII.—*Freezing point depressions and osmotic pressures of the sap of trees classified by species, locality, type, situation, altitude, and date of collection*—Con.

[Numbers in italics represent averages of two or more determinations]

Species and locality	Type	Situation	Altitude	Date of collection	Depression of freezing point	Osmotic pressure
			Feet	*1920–1921*	*Degrees C.*	*Atmospheres*
Abies concolor (Gord.) Parry						
Beaver Creek	Aspen-fir	Eastern aspect	7,400	Sept. 16	1.28	15.4
Taylor Canyon	do	Northern aspect	5,200	Jan. 4	0.74	8.9
Do	do	do	7,800	do	0.66	8.0
Ogden, Utah		City park [a]	4,350	Jan. 25	1.04	12.5
Taylor Canyon	Aspen-fir	Northern aspect	5,200	Feb. 28	0.98	11.8
Do	do	do	7,000	do	1.06	12.8
Do	do	do	8,500	do	0.64	7.7
Picea parryana (André) Parry						
Big Cottonwood Canyon.	Aspen-fir	Canyon bottom	7,000	July 23	1.26	15.2
Do	do	do	7,200	July 19	1.37	16.5
Do	do	do	7,400	July 13	*1.42*	*17.1*
Do	do	do	7,400	July 23	1.11	13.4
Do	do	do	7,400	July 25	1.11	13.4
Do	do	Lower southern aspect	7,450	July 26	1.23	14.8
Do	do	Canyon bottom	7,700	July 24	1.16	14.0
Do	do	do	7,000	Sept. 20	0.91	11.0
Do	do	do	7,200	Sept. 22	1.00	12.0
Do	do	Lower southern aspect	7,450	Sept. 7	1.14	13.7
Do	do	Canyon bottom	7,000	Dec. 10	1.02	12.3
Do	do	do	7,200	Dec. 6	1.34	16.1
Do	do	Lower southern aspect	7,450	Dec. 8	1.40	16.8
Beaver Creek	do	Canyon bottom	7,600	Sept. 16	*1.19*	*14.3*
Big Cottonwood Canyon.	do	do [b]	7,400	July 11	*1.27*	*15.3*
Ogden, Utah		City park [a]	4,350	Jan. 25	1.16	14.0
Picea engelmanni (Parry) Engelm.						
Big Cottonwood Canyon.	Aspen-fir	Canyon bottom	7,200	July 19	*1.09*	*13.1*
Do	do	do	7,400	July 13	*1.45*	*17.4*
Do	do	Northern aspect	7,500	July 27	1.15	13.8
Do	Spruce-fir	do	8,500	July 24	*1.58*	*19.0*
Do	do	do	8,800	July 25	*1.51*	*18.2*
Do	do	Ridge top	10,000	July 15	*1.58*	*19.0*
Do	Aspen-fir	Canyon bottom	7,200	Sept. 22	1.13	13.6
Do	do	Northern aspect	8,250	Sept. 20	0.85	10.2
Do	Spruce-fir	do	8,500	Sept. 12	0.97	11.7
Do	do	do	9,600	Sept. 20	1.18	14.2
Do	do	do	10,000	Sept. 9	*1.12*	*13.5*
Do	Aspen-fir	Canyon bottom	7,200	Dec. 6	1.29	15.5
Do	do	Northern aspect	7,500	Dec. 7	1.40	16.8
Do	Spruce-fir	do	9,500	do	0.95	11.4
Beaver Creek	Aspen-fir	Canyon bottom	7,600	Sept. 16	*1.43*	*17.2*
Big Cottonwood Canyon.	do	do [b]	7,400	July 11	1.32	15.9
Do	do	do [b]	7,400	July 25	1.28	15.4
Abies lasiocarpa (Hook.) Nutt						
Big Cottonwood Canyon.	Aspen-fir	Canyon bottom	7,200	July 19	1.10	13.2
Do	do	do	7,400	July 13	1.45	17.4
Do	do	Northern aspect	7,500	July 12	1.09	13.1
Do	do	Lower southern aspect	7,450	July 26	0.88	10.6
Do	do	do	7,450	July 27	0.48	5.8
Do	do	Northern aspect	7,700	July 19	*1.51*	*18.2*
Do	Spruce-fir	do	8,500	July 24	1.53	18.4
Do	do	do	8,800	July 25	*1.26*	*15.2*
Do	do	Ridge top	10,000	July 15	*1.54*	*18.5*
Do	Aspen-fir	Canyon bottom	7,200	Sept. 22	0.75	9.0
Do	do	Lower southern aspect	7,450	Sept. 7	0.83	10.0
Do	do	Northern aspect	7,700	do	1.05	12.6
Do	do	do	8,250	Sept. 20	0.83	10.0
Do	do	Western aspect	9,600	do	0.99	11.9

[a] Planted, species exotic to this site.

[b] Planted although native to site.

TABLE VII.—*Freezing point depressions and osmotic pressures of the sap of trees classified by species, locality, type, situation, altitude, and date of collection*—Con.

[Numbers in italics represent averages of two or more determinations]

Species and locality	Type	Situation	Altitude	Date of collection	Depression of freezing point	Osmotic pressure
			Feet	*1920–1921*	*Degrees C.*	*Atmospheres*
Abies lasiocarpa (Hook.) Nutt—Con.						
Big Cottonwood Canyon.	Spruce-fir	Northern aspect	8,500	Sept. 12	0.74	8.9
Do	do	do	9,600	Sept. 20	0.98	11.8
Do	do	do	10,000	Sept. 9	0.72	8.7
Do	Aspen-fir	Canyon bottom	7,200	Dec. 6	0.86	10.4
Do	do	Lower southern aspect	7,450	Dec. 8	1.35	16.2
Do	do	Northern aspect	7,600	Dec. 7	1.30	15.6
Do	do	Western aspect	9,500	do	0.85	10.2
Do	Spruce-fir	Northern aspect	9,500	do	1.12	13.5
Beaver Creek	Aspen-fir	Eastern aspect	7,400	Sept. 16	0.87	10.5
Do	do	Canyon bottom	7,500	do	1.03	12.4
Taylor Canyon	Spruce-fir	Northern aspect	7,800	Jan. 4	0.42	5.1
Do	do	do	8,500	Feb. 28	0.74	8.9
Pinus flexilis James						
Big Cottonwood Canyon.	Western yellow pine	Southern aspect	6,400	July 21	1.74	20.9
Do	Aspen-fir	Northern aspect	7,500	July 13	1.27	15.3
Do	do	Southern aspect	10,000	July 15	*1.98*	*23.1*
Do	Western yellow pine	do	6,400	Sept. 22	1.16	14.0
Do	Aspen-fir	Northern aspect	7,700	Sept. 7	1.24	14.9
Do	do	do	8,250	Sept. 20	1.23	14.8
Do	do	Western aspect	9,600	do	1.04	12.5
Do	Spruce-fir	Northern aspect	10,000	Sept. 9	0.92	11.1
Do	Western yellow pine	Southern aspect	6,400	Dec. 10	1.14	13.7
Do	Aspen-fir	Northern aspect	7,700	Dec. 7	0.99	11.9
Do	do	Western aspect	9,500	do	1.29	15.5
Beaver Creek	do	Southern aspect	7,000	Sept. 16	1.64	19.7
Do	do	Northern aspect	7,000	Sept. 17	[c]0.89	10.7
Taylor Canyon	do	Southern aspect	7,600	Jan. 4	0.79	9.5
Do	do	do	8,500	Feb. 28	0.54	6.5
Do	do	Northern aspect	8,500	do	0.67	8.1
Pinus contorta Loud.						
Beaver Creek	Lodgepole pine	Bench in canyon bottom.	7,000	Sept. 16	1.46	17.6
Do	do	do	7,300	do	1.52	18.3
Do	do	Flat divide	7,500	do	*1.39*	*16.7*
Do	do	Bench in canyon bottom. [b]	7,300	do	1.68	20.2
Big Cottonwood Canyon.	Aspen-fir	Canyon bottom [a]	7,400	July 7	1.42	17.1
Do	do	do	7,400	July 12	1.44	17.3
Do	do	do	7,400	Dec. 8	1.48	17.8
Pinus ponderosa Laws.						
Big Cottonwood Canyon.	Aspen-fir	Southern aspect [a]	7,200	July 23	1.15	13.8
Do	do	do	7,200	Dec. 10	1.11	13.4
Do	Chaparral	do	7,300	July 25	*1.49*	*17.9*
Do	Aspen-fir	do	7,450	July 27	1.05	12.6
Do	do	do	7,500	July 19	1.43	17.2
Do	do	Canyon bottom [a]	7,400	July 7	*1.55*	*18.6*
Do	do	do	7,400	July 27	1.35	16.2
Do	do	do	7,400	Sept. 20	*1.37*	*16.5*
Do	do	Canyon bottom under 3 feet snow [a]	7,400	Dec. 8	1.34	16.1
Do	do	Canyon bottom [a]	7,400	do	1.83	22.0
Do	do	do	7,400	July 13	*1.20*	*14.4*
Do	do	do	7,400	July 14	1.16	14.0
Do	do	Northern aspect [a]	7,450	July 19	1.42	17.1
Do	do	Canyon bottom [a]	7,400	Sept. 22	0.97	11.7
Do	do	do	7,400	Dec. 8	1.25	15.0
Ogden, Utah		City park [a]	4,350	Jan. 25	0.75	9.0
Pinus austriaca Höss.						
Ogden, Utah		City park [a]	4,350	do	*1.19*	*14.3*

[a] Planted, species exotic to this site.
[b] Planted although native to site.
[c] Sample collected after a heavy rain.

TABLE VII.—*Freezing point depressions and osmotic pressures of the sap of trees classified by species, locality, type, situation, altitude, and date of collection*—Con.

[Numbers in italics represent averages of two or more determinations]

Species and locality	Type	Situation	Altitude	Date of collection	Depression of freezing point	Osmotic pressure
			Feet	*1920–1921*	*Degrees C.*	*Atmospheres*
Pinus banksiana Lamb.						
Big Cottonwood Canyon.	Aspen-fir	Northern aspect *	7,450	July 27	1.07	12.9
Pinus laricio corsicana Hort.						
Big Cottonwood Canyon.	Aspen-fir	Northern aspect *	7,450	July 27	1.28	15.4
Pinus jeffreyi Murr.						
Big Cottonwood Canyon.	Aspen-fir	Northern aspect *	7,450	July 19	1.38	16.6
Pinus montana Mill.						
Ogden, Utah		City park *	4,350	Jan. 25	0.90	10.8
Pinus monticola Dougl.						
Big Cottonwood Canyon.	Aspen-fir	Canyon bottom *	7,400	July 7	1.41	17.0
Do	do	Northern aspect *	7,450	July 23	1.15	13.8
Pinus strobus L.						
Ogden, Utah		City park *	4,350	Jan. 25	1.23	14.8
Picea excelsa Link.						
Big Cottonwood Canyon.	Aspen-fir	Canyon bottom *	7,400	July 11	1.35	16.2
Do	do	do	7,400	July 23	1.18	14.2
Ogden, Utah		City park *	4,350	Jan. 25	*0.93*	*11.2*
Larix occidentalis Nutt.						
Big Cottonwood Canyon.	Aspen-fir	Northern aspect *	7,450	July 19	1.60	19.2
Thuja occidentalis L.						
Ogden, Utah		City park *	4,350	Jan. 25	2.72	32.6
Thuja orientalis L.						
Ogden, Utah		City park *	4,350	do	1.73	20.8
Acer grandidentatum Nutt.						
Big Cottonwood Canyon.	Stream-bank	Canyon bottom	4,500	July 21	1.64	19.7
Do	Western yellow pine	Southern aspect	6,400	do	1.33	22.0
Do	do	do	6,400	Sept. 22	*1.44*	*17.3*
Do	Aspen-fir	Lower southern aspect.	7,450	July 26	1.43	17.2
Do	do	do	7,450	Sept. 7	*1.44*	*17.3*
Do	do	Northwestern aspect	7,700	Sept. 9	1.52	18.3
Acer glabrum Torr.						
Big Cottonwood Canyon.	Aspen-fir	Northern aspect	7,500	July 13	1.17	14.1
Acer negundo L.						
Big Cottonwood Canyon.	Stream-bank	Canyon bottom	4,300	July 18	0.99	13.1
Do	do	do	4,400	July 21	1.09	13.1
Do	do	do	6,800	do	1.06	12.8

* Planted, species exotic to this site.

TABLE VII.—*Freezing point depressions and osmotic pressures of the sap of trees classified by species, locality, type, situation, altitude, and date of collection*—Con.

[Numbers in italics represent averages of two or more determinations]

Species and locality	Type	Situation	Altitude	Date of collection	Depression of freezing point	Osmotic pressure
			Feet	*1920–1921*	*Degrees C.*	*Atmospheres*
***Populus angustifolia* James**						
Big Cottonwood Canyon.	Stream-bank	Canyon bottom	4,300	July 8	1.46	17.6
Do	do	do	4,400	July 21	1.37	16.5
Do	Western yellow pine	Southern aspect	6,400	do	1.66	20.0
Do	Aspen-fir	Canyon bottom	7,400	July 14	1.54	18.5
Do	do	do	7,400	July 22	*1.67*	*20.1*
***Populus tremuloides* Michx.**						
Big Cottonwood Canyon.	Aspen-fir	Canyon bottom	7,450	July 11	*1.83*	*21.9*
Do	do	Southern aspect	7,500	July 19	2.26	27.2
Do	do	do	7,450	Sept. 6	2.37	28.5
Do	do	Northern aspect	7,500	July 13	1.74	20.9
Do	do	do	7,700	Sept. 7	2.02	24.3
Do	do	do	7,700	Sept. 9	1.83	22.0
Do	Spruce-fir	Ridge-top	10,000	July 15	*1.92*	*23.1*
Do	do	Northern aspect	10,000	Sept. 9	2.09	25.1
Beaver Creek	Lodgepole pine	Bench in canyon bottom.	7,400	Sept. 16	2.27	27.3
***Alnus tenuifolia* Nutt.**						
Big Cottonwood Canyon.	Aspen-fir	Northern aspect	7,500	July 13	1.12	13.5
***Betula fontinalis* Sarg.**						
Big Cottonwood Canyon.	Stream-bank	Canyon bottom	4,300	July 8	1.36	16.4
Do	Western yellow pine	Southern aspect	6,400	July 21	1.50	18.0
***Crataegus rivularis* Nutt.**						
Big Cottonwood Canyon.	Stream-bank	Canyon bottom	4,400	do	1.85	22.2

TABLE VIII.—*Freezing point depressions and osmotic pressures of the sap of shrubs classified by species, locality, type, situation, altitude, and date of collection*

[Figures in italics represent averages of two or more determinations]

Species and locality	Type	Situation	Altitude	Date of collection	Depression of freezing point	Osmotic pressure
			Feet	*1920–1921*	*Degrees C.*	*Atmospheres*
***Artemisia tridentata* Nutt.**						
Big Cottonwood Canyon.	Stream bank	Canyon bottom	4,300	July 8	1.36	16.4
Do	Sagebrush	Southern aspect	5,000	July 21	2.51	30.1
Do	Chaparral	do	7,600	July 19	1.66	20.0
Do	Aspen-fir	Northern aspect	7,450	July 17	1.27	15.3
Do	Sagebrush	Southern aspect	5,000	Sept. 17	2.08	25.0
Do	Chaparral	do	7,600	Sept. 6	1.82	21.9
Do	Aspen-fir	Northern aspect	8,500	Sept. 20	1.41	17.0
Do	Sagebrush	Southern aspect	5,000	Dec. 10	2.06	24.8
Do	Chaparral	do	7,500	Dec. 6	2.69	32.3
Do	Aspen-fir	Ridge top	9,000	Dec. 7	1.97	23.7
Beaver Creek	Sagebrush	Southern aspect	7,400	Sept. 16	2.73	32.8
Taylor Canyon	do	Very gentle western aspect.	4,500	Jan. 4	2.85	34.2
Do	do	Southern aspect	5,200	do	3.34	40.0
Do	do	Very gentle western aspect.	4,500	Feb. 28	2.36	28.3
Do	do	Southern aspect	5,200	do	2.40	28.8
Do	do	do	7,000	do	2.31	27.8

TABLE VIII.—*Freezing point depressions and osmotic pressures of the sap of shrubs classified by species, locality, type, situation, altitude, and date of collection*—Con.

[Figures in italics represent averages of two or more determinations]

Species and locality	Type	Situation	Altitude	Date of collection	Depression of freezing point	Osmotic pressure
			Feet	*1920–1921*	*Degrees C.*	*Atmospheres*
Purshia tridentata (Pursh) D. C.						
Big Cottonwood Canyon.	Juniper	Southern aspect	5,000	July 21	1.80	22.7
Beaver Creek	Sagebrush	do	7,400	Sept. 16	2.15	25.8
Gutierrezia filifolia Greene						
Big Cottonwood Canyon.	Sagebrush	do	5,000	Sept. 17	2.55	30.6
Rhus trilobata Nutt.						
Big Cottonwood Canyon	Stream bank	Canyon bottom	4,300	July 8	1.57	18.9
Do	Juniper	Southern aspect	5,000	July 21	1.82	21.9
Rhus cismontana Greene						
Big Cottonwood Canyon.	Stream bank	Canyon bottom	4,300	July 8	1.37	16.5
Do	do	Southern aspect	4,500	July 21	1.56	18.8
Quercus utahensis (DC.) Rydb.						
Big Cottonwood Canyon.	Stream bank	Canyon bottom	4,300	July 8	1.66	20.0
Do	do	Southern aspect	4,500	July 21	1.84	22.1
Do	Western yellow pine	Steep southern aspect	6,400	do	2.07	24.9
Do	Chaparral	Southern aspect	7,550	July 16	1.80	21.6
Do	Juniper	do	5,200	Sept. 17	1.90	22.8
Do	Western yellow pine	do	6,400	Sept. 22	1.68	20.2
Do	Chaparral	do	7,550	Sept. 6	1.95	23.4
Do	Aspen-fir	Northwestern aspect	7,700	Sept. 9	1.90	22.8
Beaver Creek	Chaparral	Southern aspect	7,400	Sept. 16	2.00	24.0
Prunus melanocarpa (A. Nels.) Rydb.						
Big Cottonwood Canyon.	Stream bank	Canyon bottom	4,300	July 8	1.81	21.8
Do	Chaparral	Southern aspect	4,500	July 21	2.00	24.0
Do	do	do	7,550	July 26	1.74	20.9
Do	Aspen-fir	Northern aspect	7,450	July 17	1.52	18.3
Do	Spruce-fir	Ridge top	10,000	July 15	*1.95*	*23.4*
Do	Chaparral	Southern aspect	7,550	Sept. 7	1.55	18.6
Do	do	do	7,550	Sept. 12	1.75	21.0
Do	Aspen-fir	Northwestern aspect	7,700	Sept. 9	1.87	22.5
Do	do	Northern aspect	7,450	Sept. 13	1.20	14.4
Do	Spruce-fir	Eastern aspect	9,000	Sept. 9	2.09	25.1
Cercocarpus ledifolius Nutt.						
Big Cottonwood Canyon.	Chaparral	Southern aspect	6,400	July 21	*2.71*	*32.5*
Do	do	do	7,550	July 16	1.50	18.0
Do	do	do	7,600	July 26	1.56	18.8
Do	do	do	6,400	Sept. 22	1.19	14.3
Do	do	do	7,550	Sept. 6	1.58	19.0
Do	do	do	6,400	Dec. 10	2.67	32.0
Do	do	do	7,550	Dec. 6	2.60	31.2
Do	do	do	5,200	Jan. 4	2.79	33.5
Taylor Canyon	do	do	7,600	do	2.99	35.9
Do	do	do	7,000	Feb. 28	2.66	31.9
Do	do	do	8,500	do	2.60	31.2
Cercocarpus Montanus Raf.						
Beaver Creek	Chaparral	Ridge top	7,100	Sept. 17	2.04	24.5

TABLE VIII.—*Freezing point depressions and osmotic pressures of the sap of shrubs classified by species, locality, type, situation, altitude, and date of collection*—Con.

[Figures in italics represent averages of two or more determinations]

Species and locality	Type	Situation	Altitude	Date of collection	Depression of freezing point	Osmotic pressure
			Feet	*1920–1921*	*Degrees C.*	*Atmospheres*
Sericotheca dumosa (Nutt.) Rydb.						
Big Cottonwood Canyon.	Chaparral	Southern aspect	6,400	July 21	*3.13*	*37.5*
Do	do	do	6,400	Sept. 22	3.23	38.7
Odostemon repens (Lindl.) Cocker.						
Big Cottonwood Canyon.	Sagebrush	Southern aspect	4,500	July 21	1.98	23.8
Do	Chaparral	do	6,400	do	2.51	30.1
Do	Aspen-fir	Northern aspect	7,450	July 23	1.27	15.3
Do	Spruce-fir	Ridge-top	10,000	July 15	1.46	17.6
Do	Chaparral	Southern aspect	7,550	July 19	1.76	21.2
Do	do	do	7,550	Sept. 7	1.60	19.2
Do	do	do	7,550	Sept. 12	1.65	19.8
Do	Aspen-fir	Northern aspect	7,450	Sept. 20	1.57	18.9
Do	Chaparral	Southern aspect	6,400	Dec. 10	2.59	31.1
Ceanothus velutinus Dougl.						
Big Cottonwood Canyon.	Aspen-fir	Northern aspect	7,450	July 11	1.06	12.8
Do	Chaparral	Southern aspect	7,550	July 16	1.35	16.2
Do	Aspen-fir	Northern aspect	7,450	Sept. 20	1.46	17.6
Do	Chaparral	Southern aspect	7,550	Sept. 6	1.84	22.1
Do	Aspen-fir	Northwestern aspect	7,700	Sept. 9	0.96	11.6
Do	Chaparral	Southern aspect	6,400	Dec. 10	3.03	36.4
Do	do	do	7,550	Dec. 6	2.58	31.0
Beaver Creek	do	do	7,400	Sept. 16	2.10	25.2
Taylor Canyon	Aspen-fir	Northern aspect	5,200	Jan. 4	2.99	35.9
Do	Chaparral	Southern aspect	5,200	Feb. 28	2.73	32.8
Do	Aspen-fir	Northern aspect	5,200	do	*2.47*	*29.7*
Pachystima myrsinites (Pursh) Raf.						
Big Cottonwood Canyon.	Aspen-fir	Northern aspect	7,500	July 13	1.33	16.0
Do	Chaparral	Southern aspect	7,550	July 19	1.41	17.0
Do	Aspen-fir	Northern aspect	7,450	Sept. 20	1.24	14.9
Do	do	Northwestern aspect	7,700	Sept. 9	1.16	14.0
Do	Chaparral	Southern aspect	7,550	Sept. 7	1.38	16.6
Do	Aspen-fir	Southern aspect (under shade).	7,450	Sept. 10	*0.66*	*8.0*
Do	do	do	7,450	Sept. 12	0.77	9.3
Do	Spruce-fir	Northern aspect (under shade).	8,500	do	*0.57*	*6.9*
Do	do	Eastern aspect (open)	9,000	Sept. 9	0.78	9.4
Do	Chaparral	Southern aspect	7,550	Dec. 6	2.00	24.0
Do	Aspen-fir	Ridge-top	9,000	Dec. 7	1.94	23.3
Beaver Creek	do	Southern aspect	7,400	Sept. 16	1.50	18.0
Taylor Canyon	do	Northern aspect	5,200	Jan. 4	2.15	25.8
Do	do	do	5,200	Feb. 28	1.67	20.1
Amelanchier alnifolia Nutt.						
Big Cottonwood Canyon.	Aspen-fir	Northern aspect	7,450	July 12	1.42	17.1
Do	Chaparral	Southern aspect	7,550	July 19	2.01	24.2
Do	do	do	7,550	Sept. 6	1.53	18.4
Do	do	do	7,550	Sept. 12	1.74	20.9
Do	Aspen-fir	Northern aspect	7,450	do	1.24	14.9
Do	Spruce-fir	Northern aspect (open).	8,500	do	1.70	20.4
Cornus stolonifera Michx.						
Big Cottonwood Canyon.	Aspen-fir	Northern aspect	7,500	July 13	1.30	15.6

TABLE VIII.—*Freezing point depressions and osmotic pressures of the sap of shrubs classified by species, locality, type, situation, altitude, and date of collection*—Con.

[Figures in italics represent averages of two or more determinations]

Species and locality	Type	Situation	Altitude	Date of collection	Depression of freezing point	Osmotic pressure
Dasiphora fruticosa (L.) Rydb.			*Feet*	*1920–1921*	*Degrees C.*	*Atmospheres*
Beaver Creek	Lodgepole pine	Very gentle southern aspect.	7,400	Sept. 16	1.70	20.4
Grossularia inermis (Rydb.) Coville and Britton						
Big Cottonwood Canyon.	Aspen-fir	Northern aspect	7,450	July 19	1.21	14.6
Juniperus communis L.						
Beaver Creek	Aspen-fir	Very gentle northern aspect.	7,300	Sept. 16	1.67	20.1
Do	Lodgepole pine	Very gentle eastern aspect.	7,400	...do	1.26	15.2
Big Cottonwood Canyon.	Spruce-fir	Northern aspect	10,000	Sept. 9	0.68	8.2
Lepargyrea argentea (Nutt) Greene						
Big Cottonwood Canyon.	Aspen-fir	Northern aspect	7,450	Sept. 12	1.40	16.8
Lepargyrea canadensis (L.) Greene						
Big Cottonwood Canyon.	Aspen-fir	Northern aspect	7,450	July 12	1.17	14.1
Lonicera involucrata (Richards.) Banks						
Big Cottonwood Canyon.	Aspen-fir	Northern aspect	7,450	July 11	1.74	20.9
Do	...do	...do	7,500	July 13	*1.89*	*23.0*
Do	...do	...do	7,450	Sept. 12	1.49	17.9
Do	Spruce-fir	...do	8,800	July 25	1.49	17.9
Do	...do	...do	8,950	Sept. 9	1.39	16.9
Lonicera utahensis S. Wats.						
Big Cottonwood Canyon.	Aspen-fir	Northern aspect	7,450	July 22	1.47	17.7
Do	...do	...do	7,450	Sept. 12	1.28	15.4
Do	Spruce-fir	...do	8,950	Sept. 9	1.40	16.8
Opulaster malvaceus (Greene) Kuntze						
Big Cottonwood Canyon.	Aspen-fir	Northern aspect	7,500	July 13	1.55	18.6
Do	...do	...do	7,450	Sept. 12	1.53	18.4
Do	Spruce-fir	Northern aspect (open).	8,500	...do	1.62	19.5
Ribes lacustre (Pers.) Poir.						
Big Cottonwood Canyon.	Aspen-fir	Northern aspect	7,450	July 19	1.16	14.0
Ribes montigenum McClatchie						
Big Cottonwood Canyon.	Spruce-fir	Open ridge top	10,000	July 15	1.44	17.3
Ribes viscosissimum Pursh.						
Big Cottonwood Canyon.	Aspen-fir	Northern aspect	7,450	July 12	1.40	16.8

TABLE VIII.—*Freezing point depressions and osmotic pressures of the sap of shrubs classified by species, locality, type, situation, altitude, and date of collection*—Con.

[Figures in italics represent averages of two or more determinations]

Species and locality	Type	Situation	Altitude	Date of collection	Depression of freezing point	Osmotic pressure
			Feet	*1920–1921*	*Degrees C.*	*Atmospheres*
Ribes wolfii Rothrock.						
Big Cottonwood Canyon.	Aspen-fir	Northern aspect	7,450	July 19	1.27	15.3
Do	Spruce-fir	Northern aspect (open).	10,000	July 15	1.36	16.4
Rosa fendleri Crepin						
Big Cottonwood Canyon.	Aspen-fir	Northern aspect	7,500	July 13	*1.30*	*15.6*
Do	do	Southern aspect	7,450	July 19	*1.31*	*15.8*
Do	do	do	7,450	July 26	1.48	17.8
Rubus parviflorus Nutt						
Big Cottonwood Canyon.	Aspen-fir	Northern aspect	7,450	July 12	1.12	13.5
Do	Spruce-fir	Eastern aspect	9,000	Sept. 9	1.14	13.7
Rubus leucodermis Dougl.						
Big Cottonwood Canyon.	Aspen-fir	Northern aspect	7,500	Sept. 13	0.79	9.5
Salix scouleriana Barratt						
Big Cottonwood Canyon.	Aspen-fir	Northern aspect	7,500	July 13	1.61	19.4
Salix subcaerulea Piper						
Big Cottonwood Canyon.	Spruce-fir	Northern aspect	8,950	Sept. 9	1.46	17.6
Sambucus melanocarpa A. Gray						
Big Cottonwood Canyon.	Aspen-fir	Northern aspect	7,500	July 13	1.13	13.6
Do	Spruce-fir	Ridge-top	10,000	July 15	1.12	13.5
Do	Aspen-fir	Northern aspect	7,500	Sept. 13	1.05	12.6
Sambucus coerulea Raf. (=*S. glauca* Nutt.)						
Big Cottonwood Canyon.	Aspen-fir	Southern aspect	7,450	July 26	1.36	16.4
Do	do	do	7,450	Sept. 7	1.26	15.2
Do	do	Northern aspect	7,450	Sept. 12	1.28	15.4
Do	Chaparral	Southern aspect	7,550	do	1.46	17.6
Sambucus microbotrys Rydb.						
Big Cottonwood Canyon.	Spruce-fir	Northern aspect	8,850	Sept. 9	1.15	13.8
Sorbus scopulina Greene						
Big Cottonwood Canyon.	Aspen-fir	Northern aspect	7,500	July 13	*1.84*	*22.1*
Symphoricarpos albus (L.) Blake (=*S. racemosus* Michx.)						
Big Cottonwood Canyon.	Aspen-fir	Northern aspect	7,500	July 13	1.91	23.0
Symphoricarpos vaccinioides Rydb.						
Big Cottonwood Canyon.	Aspen-fir	Southern aspect	7,450	July 19	*1.70*	*20.4*
Do	do	do	7,450	Sept. 7	1.67	20.1

TABLE VIII.—*Freezing point depressions and osmotic pressures of the sap of shrubs classified by species, locality, type, situation, altitude, and date of collection*—Con.

[Figures in italics represent averages of two or more determinations]

Species and locality	Type	Situation	Altitude	Date of collection	Depression of freezing point	Osmotic pressure
Symphoricarpos oreophilus A. Gray			*Feet*	*1920–1921*	*Degrees C.*	*Atmospheres*
Big Cottonwood Canyon.	Aspen-fir	Northern aspect	7,450	July 22	1.44	17.3
Do	do	do	7,700	Sept. 9	1.34	16.1
Do	Spruce-fir	Eastern aspect (open)	9,000	do	2.05	24.6
Do	do	Ridge-top	10,000	July 15	1.67	20.1
Arctostaphylos uva-ursi (L.) Spreng.						
Big Cottonwood Canyon.	Spruce-fir	do	10,000	Sept. 9	0.68	8.2
Taxus canadensis Marshall						
Ogden, Utah		City park [a]	4,350	Jan. 25	0.85	10.2

[a] Exotic to this site, planted.

TABLE IX.—*Freezing point depressions and osmotic pressures of the sap of herbaceous plants, including grasses and a moss on Big Cottonwood Canyon watershed, classified by species, type, situation, altitude, and date of collection*

[Figures in italics represent averages of two or more determinations]

Species and type	Situation	Altitude	Date of collection	Depression of freezing point	Osmotic pressure
Achillea lanulosa Nutt.		*Feet*	*1920*	*Degrees C.*	*Atmospheres*
Aspen-fir	Northern aspect	7,450	Sept. 10	0.86	10.4
Aconitum bakeri Greene					
Aspen-fir	Northern aspect	7,450	July 26	0.90	10.8
Actaea arguta Nutt.					
Spruce-fir	Northern aspect	9,000	Sept. 9	1.04	12.5
Agastache urticifolia (Benth.) Kuntze					
Spruce-fir	Northern aspect	10,000	July 15	1.16	14.0
Do	Northern aspect (open)	8,850	Sept. 9	1.38	16.6
Amblystegium varium (Hedw.) Lindb.					
Stream bank	Edge of water	9,000	July 27	0.22	2.7
Do	do	7,400	Sept. 21	0.42	5.1
Apocynum androsaemifolium L.					
Chaparral	Southern aspect	6,400	July 21	1.71	20.6
Aspen-fir	do	7,450	July 26	1.41	17.0
Aquilegia caerulea albiflora A. Gray					
Spruce-fir	Ridge-top	10,000	July 15	*1.40*	*16.8*
Artemisia gnaphaloides Nutt.					
Spruce-fir	Ridge-top	10,000	July 15	1.06	12.8
Chaparral	Southern exposure	6,400	Sept. 23	2.04	24.5
Spruce-fir	Northern aspect	8,900	Sept. 9	0.96	11.6

TABLE IX.—*Freezing point depressions and osmotic pressures of the sap of herbaceous plants, including grasses and a moss on Big Cottonwood Canyon watershed, classified by species, type, situation, altitude, and date of collection*—Con.

[Figures in italics represent averages of two or more determinations]

Species and type	Situation	Altitude	Date of collection	Depression of freezing point	Osmotic pressure
		Feet	*1920*	*Degrees C.*	*Atmospheres*
Aster eatonii (A. Gray) Howell					
Aspen-fir	Northern aspect	7,450	Sept. 10	*0.93*	*11.2*
Aster adscendens Lindl.					
Spruce-fir	Eastern aspect	9,000	Sept. 9	0.82	9.9
Aster engelmannii A. Gray (= *Eucephalus engelmannii* (A. Gray) Greene)					
Spruce-fir	Eastern aspect	8,950	do	*1.48*	*17.8*
Aster glaucus T. & G. (= *Eucephalus glaucus* Nutt.)					
Chaparral	Southern aspect	7,550	July 26	1.42	17.1
Aspen-fir	do	7,450	Sept. 7	1.29	15.5
Atragene columbiana Nutt. (*Clematis columbiana* ((Nutt.) Torr. & Gray)					
Aspen-fir	Northern aspect	7,450	July 12	1.37	16.5
Balsamorrhiza sagittata (Pursh) Nutt.					
Chaparral	Southern aspect	7,550	July 16	1.73	20.8
Do	do	7,550	Sept. 6	1.76	21.2
Bromus richardsonii Link.					
Spruce-fir	Northern aspect	8,950	Sept. 12	*1.14*	*13.7*
Caltha leptosepala Hook.					
Spruce-fir	Northern aspect	9,500	July 15	0.99	11.9
Castilleja lancifolia Rydb.					
Aspen-fir	Northern aspect	7,500	July 13	1.71	20.6
Castilleja linariaefolia Benth.					
Chaparral	Southern aspect	7,500	July 19	1.91	23.0
Do	do	7,500	Sept. 6	*1.83*	*22.0*
Do	do	7,500	Sept. 7	2.23	26.8
Castilleja miniata Dougl.					
Aspen-fir	Northern aspect	7,450	July 22	1.55	18.6
Castilleja rhexifolia Rydb.					
Spruce-fir	Northern aspect	10,600	July 15	1.65	19.8
Do	Eastern aspect	8,950	Sept. 9	1.89	22.7
Chamaenerion angustifolium (L) Scop.					
Aspen-fir	Northern aspect	7,450	July 17	0.80	9.6
Spruce-fir	Eastern aspect	8,950	Sept. 9	0.91	11.0
Chrysopsis fulcrata Greene					
Spruce-fir	Eastern aspect	9,000	do	0.99	11.9
Cirsium undulatum (Nutt.) Spreng.					
Aspen-fir	Lower southern aspect	7,450	Sept. 7	1.24	14.9
Drymocallis glandulosa (Nutt.) Rydb.					
Aspen-fir	Northern aspect	7,450	July 22	1.19	14.3
Spruce-fir	do	9,000	July 25	*0.77*	*9.3*
Do	Northern aspect (open)	10,000	July 15	*1.31*	*15.8*
Aspen-fir	Lower southern aspect	7,450	Sept. 6	*0.85*	*10.2*
Spruce-fir	Eastern aspect, (open)	8,850	Sept. 9	1.45	17.4

TABLE IX.—*Freezing point depressions and osmotic pressures of the sap of herbaceous plants, including grasses and a moss on Big Cottonwood Canyon watershed, classified by species, type, situation, altitude, and date of collection*—Con.

[Figures in italics represent averages of two or more determinations]

Species and type	Situation	Altitude	Date of collection	Depression of freezing point	Osmotic pressure
		Feet	*1920*	*Degrees C.*	*Atmospheres*
Elephantella groenlandica (Retz.) Rydb. (= *Pedicularis groenlandica* Retz.)					
Spruce-fir	Northern aspect	8,800	July 25	*1.15*	*13.8*
Equisetum laevigatum A. Br.					
Chaparral	Southern aspect	6,400	July 21	1.25	15.0
Erigeron speciosus (Lindl.) DC.					
Spruce-fir	Northern aspect	8,950	Sept. 9	0.99	11.9
Eriogonum heracleoides Nutt.					
Spruce-fir	Eastern aspect	9,000	...do....	1.04	12.5
Eriogonum neglectum Greene					
Chaparral	Southern aspect	7,500	July 19	1.80	21.6
Do	...do	7,500	Sept. 6	*1.46*	*17.6*
Festuca confinis Vasey					
Chaparral	Southern aspect	7,500	Sept. 12	1.38	19.0
Fragaria platypetala Rydb.					
Aspen-fir	Northern aspect	7,450	July 22	1.11	13.4
Do	Northern aspect, under aspen.	7,450	Sept. 13	0.49	5.9
Frasera speciosa Dougl.					
Aspen-fir	Northern aspect	7,450	July 22	1.12	13.5
Geranium viscosissimum F. & M.					
Aspen-fir	Lower southern aspect	7,450	July 26	*1.16*	*14.0*
Do	Northern aspect	7,500	July 13	1.04	12.5
Do	...do	7,500	Sept. 13	0.72	8.7
Gilia aggregata (Pursh) Spreng.					
Spruce-fir	Northern aspect, open	8,850	Sept. 12	1.26	15.2
Heracleum lanatum Michx.					
Aspen-fir	Northern aspect	7,450	July 19	1.00	12.0
Humulus lupulus neomexicanus Nels. & Cockerell					
Aspen-fir	Northern aspect	7,450	July 27	0.85	10.2
Ivesia gordonii (Hook) T. & G. (= *Horkelia gordonii* Hook.)					
Spruce-fir	Eastern aspect, open	9,000	Sept. 9	0.89	10.7
Lappula floribunda (Lehm.) Greene					
Aspen-fir	Northern aspect	7,450	July 27	0.70	8.4
Spruce-fir	Ridge-top	10,000	July 15	0.81	9.8
Lathyrus coriaceus White					
Spruce-fir	Northern aspect, open	10,000	July 15	0.93	11.2
Linum lewisii Pursh.					
Spruce-fir	Eastern aspect, open	9,000	Sept. 9	1.40	16.8
Lithospermum ruderale Dougl. (= *L. pilosum* Nutt.)					
Aspen-fir	Lower southern aspect	7,450	Sept. 6	1.18	14.2

TABLE IX.—*Freezing point depressions and osmotic pressures of the sap of herbaceous plants, including grasses and a moss on Big Cottonwood Canyon watershed, classified by species, type, situation, altitude, and date of collection*—Con.

[Figures in italics represent averages of two or more determinations]

Species and type	Situation	Altitude	Date of collection	Depression of freezing point	Osmotic pressure
		Feet	*1920*	*Degrees C.*	*Atmospheres*
Lupinus alpestris A. Nels.					
Spruce-fir	Northern aspect	10,000	July 15	0.90	10.8
Do	Eastern aspect	8,900	Sept. 9	1.09	13.1
Machaeranthera viscosa (Nutt.) Greene					
Chaparral	Southern aspect	7,500	Sept. 7	1.86	22.4
Macronema watsoni (A. Gray) Greene					
Chaparral	Southern aspect	6,400	Sept. 22	1.72	20.7
Madronella oblongifolia Rydb.					
Spruce-fir	Ridge-top	10,000	July 15	1.15	13.8
Do	Eastern exposure, open	9,000	Sept. 9	1.02	12.3
Mertensia sampsonii Tidestrom					
Aspen-fir	Northern aspect	7,500	July 13	1.00	12.0
Spruce-fir	Ridge-top	10,000	July 15	0.83	10.0
Do	Eastern aspect, open	9,000	Sept. 9	0.97	11.7
Mimulus guttatus DC.					
Spruce-fir	Wet meadow	8,800	July 25	0.58	7.0
Orthocarpus tolmiei H. & A.					
Aspen-fir	Lower southern aspect	7,450	Sept. 7	1.87	22.5
Spruce-fir	Northern aspect, open	8,850	Sept. 9	*1.76*	*21.2*
Penstemon cyananthus Hook.					
Spruce-fir	Northern aspect, open	8,800	July 25	1.40	16.8
Penstemon humilis Nutt.					
Chaparral	Southern aspect	7,500	July 26	2.05	24.6
Polemonium occidentale Greene					
Aspen-fir	Northern aspect	7,500	July 19	1.15	13.8
Potentilla filipes Rydb.					
Aspen-fir	Northern aspect	7,500	July 13	1.21	14.6
Potentilla nuttallii Lehm.					
Spruce-fir	Northern aspect, wet ground.	8,950	Sept. 9	0.87	10.5
Ranunculus maximus Greene					
Spruce-fir	Northern aspect	8,800	July 25	1.05	12.6
Rudbeckia occidentalis Nutt.					
Aspen-fir	Northern aspect	7,450	July 19	0.91	11.0
Spruce-fir	Eastern aspect	8,900	Sept. 9	0.91	11.0
Sedum stenopetalum Pursh.					
Aspen-fir	Southern aspect	7,450	July 26	0.53	6.4
Do	....do	7,450	Sept. 7	0.70	8.4
Senecio serra Hook.					
Aspen-fir	Northern aspect	7,450	July 26	0.92	11.1
Solidago trinerrata Greene					
Chaparral	Southern aspect	6,400	Sept. 22	2.27	27.3

TABLE IX.—*Freezing point depressions and osmotic pressures of the sap of herbaceous plants, including grasses and a moss on Big Cottonwood Canyon watershed, classified by species, type, situation, altitude, and date of collection*—Con.

[Figures in italics represent averages of two or more determinations]

Species and type	Situation	Altitude	Date of collection	Depression of freezing point	Osmotic pressure
		Feet	*1920*	*Degrees C.*	*Atmospheres*
Stipa nelsonii Scribner					
Spruce-fir	Northern aspect, open	8,850	Sept. 12	1.33	16.0
Thalictrum fendleri Engelm.					
Aspen-fir	Northern aspect	7,450	July 17	1.51	18.2
Spruce-fir	Ridge-top	10,000	July 15	1.43	17.2
Do	Eastern aspect, open	8,950	Sept. 9	1.41	17.0
Tithymalus robustus (Engelm.) Small (= *Euphorbia robusta* (Engelm.) Small)					
Chaparral	Southern aspect	7,500	July 26	1.56	18.8
Urtica gracilis Ait.					
Aspen-fir	Northern aspect	7,450	July 23	0.88	10.6
Vagnera liliacea (Greene) Rydb.					
Aspen-fir	Northern aspect	7,450	July 27	0.98	11.8
Valeriana ceratophylla (Hook.) Piper					
Spruce-fir	Northern aspect	8,800	July 25	0.97	11.7
Veratrum speciosum Rydb.					
Spruce-fir	Northern aspect	8,800	July 25	0.97	11.7
Viguiera multiflora (Nutt.) Blake (= *Gymnolomia multiflora* (Nutt.) Benth. & Hook.)					
Chaparral	Southern aspect	7,500	Sept. 7	1.57	18.9
Spruce-fir	Northern aspect	8,950	Sept. 9	1.02	12.3
Zauschneria garretti A. Nels.					
Chaparral	Southern aspect	6,400	Sept. 22	1.16	14.0

TABLE X.—*Summary of sap concentrations of all species by type, growth form, and season, Wasatch Mountain series*

Type and growth form.	Season.	Depression of freezing point.	Osmotic pressure.
		Degrees C.	*Atmospheres*
Stream bank:			
Trees	Summer	1.36	16.4
Shrubs	do	1.60	19.2
Moss	do	0.22	2.7
Do	Autumn	0.42	5.1
Sagebrush:			
Shrubs	Summer	2.51	30.1
Do	Autumn	2.38	28.6
Do	Winter	2.75	33.0
Do	Spring	2.35	28.2
Juniper:			
Trees	Summer	2.19	26.3
Do	Autumn	1.32	15.9
Do	Winter	2.26	27.2
Shrubs	Summer	1.86	22.4
Do	Autumn	1.90	22.8
Western yellow pine:			
Trees	Summer	1.85	22.2
Do	Autumn	1.45	17.4
Do	Winter	1.41	17.0
Shrubs	Summer	2.07	24.9
Do	Autumn	1.68	20.2

TABLE X.—*Summary of sap concentrations of all species by type, growth, form, and season, Wasatch Mountain series*—Continued

Type and growth form.	Season.	Depression of freezing point.	Osmotic pressure.
		Degrees C.	*Atmospheres*
Chaparral:			
Trees	Summer	1.60	19.2
Do	Autumn	0.93	11.2
Do	Winter	2.17	26.1
Shrubs	Summer	1.93	23.2
Do	Autumn	1.77	21.3
Do	Winter	2.66	31.9
Herbs	Summer	1.68	20.2
Do	Autumn	1.77	21.3
Aspen-fir:			
Trees	Summer	1.39	16.7
Do	Autumn	1.23	14.8
Do	Winter	1.06	12.8
Shrubs	Summer	1.42	17.1
Do	Autumn	1.32	15.9
Do	Winter	2.20	26.4
Herbs	Summer	1.08	13.0
Do	Autumn	0.99	11.9
Spruce-fir:			
Trees	Summer	1.56	18.8
Do	Autumn	1.10	13.2
Do	Winter	0.81	9.8
Shrubs	Summer	1.50	18.0
Do	Autumn	1.29	15.5
Herbs	Summer	1.05	12.6
Do	Autumn	1.15	13.8

TABLE XI.—*Freezing point depressions and osmotic pressures of the sap of trees on Ephraim Canyon watershed, central Utah, classified by species, type, situation, altitude, and date of collection*

[Figures in italics represent averages of two or more determinations]

Species and type	Situation	Altitude	Date of collection	Depression of freezing point	Osmotic pressure
Pinus edulis Engelm.		*Feet*	*1921*	*Degrees C.*	*Atmospheres*
Pinon-juniper	Outwash from canyon	5,800	July 21	1.86	22.4
Do	Southern aspect	6,000	July 23	1.72	20.7
Do	...do	7,400	July 19	1.32	15.9
Do	...do	7,400	July 26	1.70	20.4
Juniperus utahensis (Engelm.) Lemm.					
Pinon-juniper	Outwash from canyon	5,800	July 21	*1.90*	*22.8*
Do	Southern aspect	6,000	July 23	1.33	16.0
Oak brush	...do	7,200	July 26	1.27	15.3
Juniperus scopulorum Sarg.					
Oak brush	Northern aspect	7,400	July 19	1.42	17.1
Pinus ponderosa scopulorum Engelm.					
Oak brush	Sagebrush flat [b]	7,600	July 19	1.91	23.0
Do	...do	7,400	...do	1.68	20.2
Do	Southern aspect [a]	7,400	...do	1.54	18.5
Pinus ponderosa Laws.					
Oak brush	Northern aspect [a]	7,400	July 19	1.47	17.7
Do	Sagebrush flat [a]	7,400	...do	1.65	19.8

[a] Exotic to this site, planted.

[b] Planted, although native to site.

TABLE XI.—*Freezing point depressions and osmotic pressures of the sap of trees on Ephraim Canyon watershed, central Utah, classified by species, type, situation, altitude, and date of collection*—Continued

[Figures in italics represent averages of two or more determinations]

Species and type	Situation	Altitude	Date of collection	Depression of freezing point	Osmotic pressure
		Feet	*1921*	*Degrees C.*	*Atmospheres*
Pseudotsuga taxifolia (Lam.) Britton					
Oak brush	Northern aspect [b]	7,400	July 19	1.65	19.8
Do	....do	7,400	July 26	1.24	14.9
Aspen-fir	Western aspect	8,800	July 14	1.92	23.1
Do	....do	8,800	July 22	1.66	20.0
Do	Northern aspect	8,800	July 24	1.39	16.7
Abies concolor (Gord.) Parry					
Oak brush	Northern aspect	7,400	July 26	1.55	18.6
Aspen-fir	Western aspect	8,800	July 14	1.65	19.8
Do	Northern aspect	8,800	July 24	1.20	14.4
Picea parryana (André) Parry					
Oak brush	Northern aspect	7,400	July 26	1.04	12.5
Aspen-fir	Western aspect	8,700	July 14	1.43	17.2
Do	Northern aspect	8,800	July 24	1.08	13.0
Pinus flexilis James					
Aspen-fir	Northern aspect	8,800	July 24	1.10	13.2
Spruce-fir	Southern aspect	10,000	July 18	1.20	14.4
Do	....do	10,000	July 22	*1.14*	*13.7*
Picea engelmanni (Parry) Engelm.					
Aspen-fir	Western aspect	8,800	July 14	1.23	14.8
Do	Northern aspect	8,800	July 24	0.97	11.7
Spruce-fir	....do	10,000	July 18	1.37	16.5
Do	....do	10,000	July 22	*1.17*	*14.1*
Do	Southern aspect	10,000	July 18	1.16	14.0
Do	....do	10,000	July 22	*1.15*	*13.8*
Abies lasiocarpa (Hook.) Nutt.					
Oak brush	Northern aspect	7,500	July 26	1.24	14.9
Aspen-fir	Western aspect	8,700	July 14	1.37	16.5
Do	Northern aspect	8,800	July 24	1.01	12.2
Spruce-fir	....do	10,000	July 15	1.19	14.3
Do	....do	10,000	July 18	0.65	7.8
Do	....do	10,000	July 22	0.78	*9.4*
Do	Southern aspect	10,000	July 18	1.36	16.4
Do	....do	10,000	July 22	0.98	*11.8*
Acer grandidentatum Nutt.					
Oak brush	Northern aspect	7,400	July 19	1.38	16.6
Acer glabrum Torr.					
Aspen-fir	Northern aspect	8,800	July 24	1.07	12.9
Populus tremuloides Michx.					
Oak brush	Northern aspect	7,800	July 26	1.96	23.6
Aspen-fir	Western aspect	8,800	July 14	2.29	27.5
Spruce-fir	Southern aspect	9,500	....do	2.17	26.1
Do	....do	9,500	July 18	2.19	26.3

[b] Planted, although native to site.

TABLE XII.—*Freezing point depressions and osmotic pressures of the sap of shrubs on Ephraim Canyon watershed, central Utah, classified by species, type, situation, altitude, and date of collection*

[Figures in italics represent averages of two or more determinations]

Species and type	Situation	Altitude	Date of collection	Depression of freezing point	Osmotic pressure
		Feet	*1921*	*Degrees C.*	*Atmospheres*
***Atriplex confertifolia* S. Wats.**					
Greasewood-shadscale	Alkali flat	5,600	July 23	*5.14*	*61.4*
Pinon-juniper	Southern aspect	6,200	do	2.62	31.4
***Atriplex tridentata* O. Kuntze**					
Greasewood-shadscale	Alkali flat	5,600	July 23	5.65	67.5
***Sarcobatus vermiculatus* (Hook.) Torr.**					
Greasewood-shadscale	Alkali flat	5,600	July 23	2.52	30.3
Sagebrush	Outwash from canyon	5,800	do	2.23	26.8
***Eurotia lanata* (Pursh) Moq.**					
Greasewood-shadscale	Alkali flat	5,600	July 21	*2.98*	*35.8*
Oak brush	Southern aspect	7,400	July 26	1.72	20.7
***Artemisia tridentata* Nutt.**					
Sagebrush	Outwash from canyon	5,800	July 21	*2.93*	*35.2*
Do	do	5,800	July 23	*2.92*	*35.0*
Oak brush	Southern aspect	7,400	July 26	1.68	20.2
Do	Sagebrush flat	7,400	July 19	1.38	16.6
Spruce-fir	Northern aspect	10,700	July 21	*1.21*	*14.6*
***Chrysothamnus nauseosus* (Pall.) Britt.**					
Sagebrush	Outwash from canyon	5,800	July 23	1.32	15.9
Pinon-juniper	Steep southern aspect	6,000	do	1.53	18.4
Oak brush	Sagebrush flat	7,400	July 26	1.68	20.2
***Chrysothamnus puberulus* (D. C. Eaton) Greene**					
Pinon-juniper	Southern aspect	6,000	July 23	1.63	19.6
***Chrysothamnus* sp.**					
Oak brush	Southern aspect	7,400	July 26	2.16	26.0
***Chrysothamnus lanceolatus* Nutt.**					
Spruce-fir	Northern aspect	10,500	July 15	1.37	16.5
Do	do	10,500	July 21	*1.37*	*16.5*
***Ephedra viridis* Coville**					
Pinon-juniper	Southern aspect	6,000	July 23	1.23	14.8
***Rhus trilobata* Nutt.**					
Pinon-juniper	Southern aspect	6,000	July 23	1.94	23.3
***Peraphyllum ramosissimum* Nutt.**					
Pinon-juniper	Southern aspect	6,000	July 23	*2.18*	*26.2*
Oak brush	do	7,400	July 26	*2.08*	*25.0*
***Quercus utahensis* (DC.) Rydb.**					
Pinon-juniper	Southern aspect	6,000	July 23	1.64	19.7
Oak brush	Northern aspect	7,400	July 18	1.67	20.1
Do	Southern aspect	7,400	July 19	1.72	20.7
Do	do	7,400	July 26	1.54	18.5
Aspen-fir	do	8,600	July 25	1.28	15.4
***Arctostaphylos pungens* H. B. K.**					
Oak brush	Southern aspect	7,400	July 19	1.50	18.0
Aspen-fir	do	8,600	July 26	1.43	17.2
***Cercocarpus Montanus Raf.* Nutt.**					
Oak brush	Southern aspect	7,400	July 26	1.31	15.8
Aspen-fir	do	8,600	July 25	1.31	15.8

TABLE XII.—*Freezing point depressions and osmotic pressures of the sap of shrubs on Ephraim Canyon watershed, central Utah, classified by species, type, situation, altitude, and date of collection*—Continued

[Figures in italics represent averages of two or more determinations]

Species and type	Situation	Altitude	Date of collection	Depression of freezing point	Osmotic pressure
		Feet	*1921*	*Degrees C.*	*Atmospheres*
Cercocarpus ledifolius Nutt.					
Aspen-fir	Southern aspect	8,600	July 24	1.05	12.6
Ceanothus fendleri A. Gray					
Oak brush	Southern aspect	7,400	July 26	1.48	17.8
Aspen-fir	do	8,600	July 25	1.23	14.8
Amelanchier alnifolia Nutt.					
Oak brush	Northern aspect	7,400	July 19	1.58	19.0
Do	Southern aspect	7,400	do	1.89	22.7
Aspen-fir	Western aspect	8,600	July 27	1.45	17.4
Prunus melanocarpa (A. Nels.) Rydb.					
Oak brush	Northern aspect	7,400	July 19	1.50	18.0
Aspen-fir	Western aspect	8,600	July 27	1.43	17.2
Odostemon repens (Lindl.) Cocker.					
Oak brush	Northern aspect	7,400	July 19	1.39	16.7
Do	Southern aspect	7,400	July 26	1.73	20.8
Aspen-fir	do	8,600	July 25	1.41	17.0
Purshia tridentata (Pursh) D C.					
Oak brush	Southern aspect	7,400	July 26	1.39	16.7
Pachystima myrsinites (Pursh) Raf.					
Oak brush	Southern aspect	7,400	July 26	1.13	13.6
Aspen-fir	do	8,600	July 25	0.97	11.7
Rosa fendleri Crepin.					
Oak brush	Northern aspect	7,400	July 19	1.43	17.2
Aspen-fir	Southern aspect	8,600	July 25	1.20	14.4
Symphoricarpos oreophilus A. Gray					
Oak brush	Northern aspect	7,400	July 19	2.02	24.3
Do	Southern aspect	7,400	July 26	2.27	27.3
Aspen-fir	do	8,600	July 14	2.07	24.9
Spruce-fir	Northern aspect	10,000	July 22	1.76	21.2
Do	Southern aspect	9,800	do	1.98	23.8
Juniperus communis L.					
Oak brush	Northern aspect	7,400	July 26	1.01	12.2
Aspen-fir	Southern aspect	8,600	July 25	0.98	11.8
Lepargyrea canadensis (L.) Greene					
Aspen-fir	Western aspect	8,600	July 24	1.18	14.2
Lonicera involucrata (Richards.) Banks					
Aspen-fir	Western aspect	8,600	July 24	*1.49*	*17.9*
Lonicera utahensis S. Wats.					
Aspen-fir	Western aspect	8,600	July 25	1.23	14.8
Grossularia inermis (Rydb.) Coville and Britton					
Spruce-fir	Northern aspect	10,000	July 18	1.39	16.7
Do	Southern aspect	10,000	July 12	1.69	20.3
Do	do	10,000	July 15	1.59	19.1
Sambucus microbotrys Rydb.					
Spruce-fir	Northern aspect	10,000	July 18	1.08	13.0
Do	Southern aspect	10,000	July 12	*1.14*	*13.7*
Ribes cereum Dougl.					
Spruce-fir	Southern aspect	10,000	July 12	1.18	14.2

TABLE XIII.—*Freezing point depressions and osmotic pressures of the sap of herbs on Ephraim Canyon watershed, central Utah, classified by species, type, situation, altitude, and date of collection*

[Figures in italics represent averages of two or more determinations]

Species and type	Situation	Altitude	Date of collection	Depression of freezing point	Osmotic pressure
		Feet	*1921*	*Degrees C.*	*Atmospheres*
Achillea lanulosa Nutt.					
Oak brush	Northern aspect	7,400	July 19	0.75	9.0
Do	Sagebrush flat (under sage)	7,400	July 26	*1.32*	*15.9*
Do	Sagebrush flat (in open)	7,400	...do	1.49	17.9
Spruce-fir	Southern aspect	9,800	July 12	*1.36*	*16.4*
Aconitum columbianum Nutt.					
Spruce-fir	Northern aspect	10,000	July 18	0.88	10.6
Agoseris agrestis Osterh.					
Spruce-fir	Southern aspect	10,000	July 18	0.72	8.7
Agoseris sp.					
Spruce-fir	Southern aspect	10,000	July 18	0.92	11.1
Agropyron dasystachyum (Hook.) Scribn.					
Spruce-fir	Southern aspect	10,000	July 15	*1.67*	*20.1*
Agropyron riparium S. & S.					
Oak brush	Sagebrush flat	7,400	July 26	1.19	14.3
Agropyron violaceum (Hornem.) Lange					
Spruce-fir	Southern aspect	10,000	July 14	*1.41*	*17.0*
Alsine jamesiana (Torr.) Heller					
Oak brush	Northern aspect	7,400	July 26	1.21	14.6
Spruce-fir	Southern aspect	10,000	July 12	1.20	14.4
Aquilegia caerulea James					
Aspen-fir	Gentle northern aspect	8,700	July 26	1.13	13.6
Spruce-fir	Northern aspect	10,000	July 18	1.00	12.0
Do	Southern aspect	10,000	July 12	1.61	19.4
Arnica cordifolia Hook.					
Spruce-fir	Northern aspect	10,000	July 15	0.76	9.2
Artemisia discolor Dougl.					
Spruce-fir	Southern aspect	10,200	July 12	*0.92*	*11.1*
Astragalus decumbens (Nutt.) A. Gray					
Spruce-fir	Southern aspect	10,000	July 14	1.12	13.5
Bromus marginatus Nees.					
Spruce-fir	Southern aspect	10,000	July 12	*1.27*	*15.3*
Caltha rotundifolia (Huth) Greene					
Spruce-fir	Southern aspect	10,000	July 12	*1.14*	*13.7*
Cardamine cordifolia A. Gray					
Spruce-fir	Northern aspect	10,000	July 15	0.67	8.1
Castilleja flava S. Wats.					
Spruce-fir	Southern aspect	10,000	July 14	1.56	18.8
Castilleja rhexifolia Rydb.					
Spruce-fir	Northern aspect	10,000	July, 18	1.34	16.1

TABLE XIII.—*Freezing point depressions and osmotic pressures of the sap of herbs on Ephraim Canyon watershed, central Utah, classified by species, type, situation, altitude, and date of collection*—Continued

[Figures in italics represent averages of two or more determinations]

Species and type	Situation	Altitude	Date of collection	Depression of freezing point	Osmotic pressure
		Feet	*1921*	*Degrees C.*	*Atmospheres*
Chamaenerion angustifolium (L.) Scop.					
Spruce-fir	Northern aspect	10,000	July 18	0.90	10.8
Chenopodium album L.					
Aspen-fir	Northern aspect	8,700	July 25	1.17	14.1
Claytonia lanceolata Pursh					
Spruce-fir	Northern aspect (wet)	10,000	July 18	*0.38*	*4.6*
Cogswellia simplex (S. Wats.) Rydb.					
Spruce-fir	Southern aspect	10,000	July 18	1.31	15.8
Collomia linearis Nutt.					
Aspen-fir	Northern aspect	8,700	July 25	0.92	11.1
Comandra pallida A. DC.					
Oak brush	Northern aspect	7,400	July 26	1.62	19.5
Aspen-fir	Southern aspect	8,600	July 25	1.49	17.9
Delphinium barbeyi Huth					
Spruce-fir	Northern aspect	10,000	July 18	1.00	12.0
Do	Southern aspect	10,000	July 12	1.27	15.3
Delphinium menziesii DC.					
Spruce-fir	Southern aspect	10,000	July 12	1.65	19.8
Dodecatheon pauciflorum (Durand) Greene					
Spruce-fir	Northern aspect (wet)	10,000	July 15	0.71	8.6
Drymocallis glandulosa (Lindl.) Rydb.					
Spruce-fir	Northern aspect	10,000	July 18	1.19	14.3
Equisetum arvense L.					
Aspen-fir	Western aspect (wet)	8,700	July 24	0.82	9.9
Eriogonum sp.					
Spruce-fir	Southern aspect	10,000	July 18	0.97	11.7
Cheirinia aspera (Nutt.) Rydb.					
Spruce-fir	Southern aspect	10,000	do	0.76	9.2
Erythronium grandiflorum Pursh					
Spruce-fir	Northern aspect	10,000	July 22	1.03	12.4
Do	Southern aspect	10,000	July 12	1.09	13.1
Fragaria bracteata Heller					
Spruce-fir	Northern aspect	10,000	July 15	1.20	14.4
Frasera speciosa Griseb.					
Oak brush	Northern aspect	7,400	July 19	1.26	15.2
Aspen-fir	do	8,700	July 14	1.07	12.9
Galium boreale L.					
Oak brush	Northern aspect	7,400	July 19	1.19	14.3
Geranium viscosissimum F. & M.					
Oak brush	Northern aspect	7,400	July 19	1.08	13.0
Aspen-fir	do	8,700	July 14	0.95	11.4
Spruce-fir	do	10,000	July 18	0.86	10.4

TABLE XIII.—*Freezing point depressions and osmotic pressures of the sap of herbs on Ephraim Canyon watershed, central Utah, classified by species, type, situation, altitude, and date of collection*—Continued

[Figures in italics represent averages of two or more determinations]

Species and type	Situation	Altitude	Date of collection	Depression of freezing point	Osmotic pressure
		Feet	*1921*	*Degrees C.*	*Atmospheres*
Gilia micrantha (Kell.) A. Nels.					
Spruce-fir	Southern aspect	10,000	July 12	1.32	15.9
Viguiera multiflora (Nutt.) Blake					
Spruce-fir	Southern aspect	10,000	July 18	1.04	12.5
Helenium hoopesii A. Gray					
Aspen-fir	Northern aspect	8,600	July 27	0.99	11.9
Helianthella uniflora (Nutt.) T. & G.					
Spruce-fir	Northern aspect	10,000	July 21	*0.86*	*10.4*
Heracleum lanatum Michx.					
Spruce-fir	Northern aspect	10,000	July 18	1.23	14.8
Hordeum nodosum L.					
Spruce-fir	Northern aspect	10,000	July 14	1.41	17.0
Ivesia gordonii (Hook.) Torr. & Gray					
Spruce-fir	Northern aspect	10,000	July 21	1.38	16.6
Hyoscyamus niger L.					
Oak brush	Northern aspect	7,400	July 26	0.95	11.4
Iva axillaris Pursh					
Aspen-fir	Western aspect	8,700	July 27	1.12	13.5
Lathyrus leucanthus Rydb.					
Aspen-fir	Northern aspect	8,700	July 14	1.06	12.8
Spruce-fir	do	10,000	July 18	0.96	11.6
Do	Southern aspect	10,000	July 12	1.12	13.5
Laurauxia flava A. Nels.					
Spruce-fir	Southern aspect	10,000	July 18	*0.70*	8.4
Leontodon taraxacum L.					
Oak brush	Northern aspect	7,400	July 19	1.17	14.1
Do	Sagebrush flat (under sage)	7,400	do	1.26	15.2
Do	Sagebrush flat (in open)	7,400	do	1.08	13.0
Spruce-fir	Southern aspect	10,000	July 12	*0.96*	*11.6*
Lesquerella utahensis Rydb.					
Spruce-fir	Southern aspect	10,000	July 14	0.97	11.7
Ligusticum filicinum S. Wats.					
Aspen-fir	Northern aspect	8,700	July 25	1.14	13.7
Spruce-fir	do	10,000	July 18	1.21	14.6
Do	Southern aspect	10,000	do	1.32	15.9
Lupinus alpestris A. Nels.					
Aspen-fir	Northern aspect	8,700	July 14	0.85	10.2
Spruce-fir	do	10,000	July 18	0.92	11.1
Marrubium vulgare L.					
Pinon-juniper	Southern aspect	6,000	July 23	1.79	21.5

TABLE XIII.—*Freezing point depressions and osmotic pressures of the sap of herbs on Ephraim Canyon watershed, central Utah, classified by species, type, situation, altitude, and date of collection*—Continued

[Figures in italics represent averages of two or more determinations]

Species and type	Situation	Altitude	Date of collection	Depression of freezing point	Osmotic pressure
		Feet	*1921*	*Degrees C.*	*Atmospheres*
Melica spectabilis Scribn.					
Spruce-fir	Southern aspect	10,000	July 15	1.08	13.0
Mertensia sampsonii Tidestrom					
Spruce-fir	Southern aspect	10,000	July 14	0.81	9.8
Opuntia polyacantha Haw.					
Oak brush	Sagebrush flat	7,400	July 19	0.54	6.5
Orthocarpus tolmiei H. & A.					
Spruce-fir	Southern aspect	10,000	July 14	1.36	16.4
Osmorrhiza obtusa (Coult. & Rose) Fernald					
Spruce-fir	Northern aspect	10,000	July 18	1.05	12.6
Oxyria digyna (L.) Hill					
Spruce-fir	Northern aspect	10,000	July 22	0.62	7.5
Paeonia brownii Dougl.					
Aspen-fir	Western aspect [a]	8,700	July 25	1.14	13.7
Pentstemon procerus Dougl.					
Spruce-fir	Southern aspect	10,000	July 12	*1.34*	*16.1*
Phacelia sericea (Graham) A. Gray					
Spruce-fir	Northern aspect	10,000	July 15	1.41	17.0
Plantago tweedyi A. Gray					
Spruce-fir	Northern aspect	10,000	July 18	0.70	8.4
Poa nevadensis Vasey					
Spruce-fir	Southern aspect	10,000	July 24	*1.50*	*18.0*
Polemonium occidentale Greene					
Aspen-fir	Northern aspect	8,700	July 14	1.08	13.0
Spruce-fir	do	10,000	July 18	1.11	13.4
Do	Southern aspect	10,000	July 12	1.01	12.2
Polygonum douglasii Greene					
Aspen-fir	Northern aspect	8,700	July 25	0.79	9.5
Potentilla filipes Rydb.					
Spruce-fir	Southern aspect	10,000	July 12	*0.98*	*11.8*
Pseudocymopterus tidestromii Coult. & Rose					
Spruce-fir	Southern aspect	10,000	July 12	*1.32*	*15.9*
Ranunculus inamoenus Greene					
Spruce-fir	Northern aspect	10,000	July 18	1.16	14.0
Do	Southern aspect	10,000	July 15	1.46	17.6
Rudbeckia occidentalis Nutt.					
Aspen-fir	Northern aspect	8,700	July 18	0.99	11.9

[a] Exotic to this site, planted.

TABLE XIII.—*Freezing point depressions and osmotic pressures of the sap of herbs on Ephraim Conyon watershed, central Utah, classified by species, type, situation, altitude, and date of collection*—Continued

[Figures in italics represent average of two or more determinations]

Species and type	Situation	Altitude	Date of collection	Depression of freezing point	Osmotic pressure
		Feet	*1921*	*Degrees C.*	*Atmospheres*
Rumex salicifolius Weinm.					
Spruce-fir	Southern aspect	10,000	July 12	0.81	9.8
Saxifraga arguta Don.					
Spruce-fir	Northern aspect	10,000	July 18	0.86	10.4
Senecio columbianus Greene					
Spruce-fir	Northern aspect	10,000	July 15	0.96	11.6
Sophia incisa (Engelm.) Greene					
Spruce-fir	Southern aspect	10,000	July 12	*1.07*	*12.9*
Stipa lettermannii Vasey					
Oak brush	Sage brush flat	7,400	July 26	1.17	14.1
Stipa minor (Vasey) Scribn.					
Spruce-fir	Northern aspect	10,000	July 21	*1.43*	*17.2*
Do	Southern aspect	10,000	July 14	*1.66*	*20.0*
Thalictrum fendleri Engelm.					
Spruce-fir	Southern aspect	10,000	July 12	1.49	17.9
Trisetum spicatum (L.) Richter					
Spruce-fir	Southern aspect	10,000	July 15	1.33	16.0
Vagnera amplexicaulis (Nutt.) Morong.					
Aspen-fir	Northern aspect	8,700	July 24	1.17	14.1
Vagnera stellata (L.) Morong.					
Spruce-fir	Southern aspect	10,000	July 12	1.17	14.1
Valeriana ceratophylla (Hook.) Piper					
Spruce-fir	Southern aspect	10,000	July 12	0.96	11.6
Valeriana occidentalis Heller					
Spruce-fir	Northern aspect	10,000	July 18	0.89	10.7
Viola linguaefolia Nutt.					
Spruce-fir	Southern aspect	10,000	July 12	*1.09*	*13.1*
Viola neomexicana Greene					
Spruce-fir	Northern aspect	10,000	July 18	0.82	9.9
Wyethia amplexicaulis Nutt.					
Aspen-fir	Western aspect	8,600	July 26	1.83	22.0
Zygadenus venenosus S. Wats.					
Spruce-fir	Northern aspect	10,000	July 21	1.10	13.2

CORRELATION AND DISCUSSION OF RESULTS

INTERDEPENDENCE OF SAP DENSITY AND WATER RELATIONS

Of the fundamental relationships indicated by the sap concentrations of the individual species in Tables VII to IX and the summaries in Table X the most significant are connected with the water relations within the plant and between the plant and its environment. Some are capable of direct measurement and may be readily correlated, while others can not as yet be measured with precision and are accordingly difficult to interpret.

A study of the easily measured environmental factors—especially precipitation, the changes in the available moisture and the evaporation on those sites which were under investigation in the aspen-fir type in Big Cottonwood Canyon—indicates that the ability of the plant to maintain a proper balance between absorption and transpiration, even at the intermediate elevations of the aspen-fir type, is of vital importance; increasingly so with lower elevations. The Ephraim Canyon series of tests, the results of which are shown in Tables XI, XII, and XIII confirm these relations.

The Wasatch Mountain series of determinations are segregated by growth forms and species in Tables VII, VIII, and IX, while those for the Ephraim Canyon series are given in Tables XI, XII, and XIII.[14] In the case of duplicate tests made at the same time merely the averages of the determinations are given. The type, situation, altitude, date of collection, depression of the freezing point in degrees C. (Δ), and the osmotic pressure in atmospheres (P), are given for each determination. Inasmuch as the thermometric readings were taken to thousandths of a degree the depressions were also computed with the same accuracy, but the osmotic pressures were interpolated from the Harris and Gortner tables (*46*, *47*); the freezing point depressions were rounded off to the nearest hundredth and the osmotic pressures to the nearest tenth, greater precision being inconsistent with the experimental error, incidental to the collection of the samples. The osmotic concentrations for all Wasatch Mountain species upon which determinations were made are summarized in Table X by type, growth form and season of the year.

From the investigations of Livingston and his associates (*84*, *85*, *88*, *89*) it is evident that when the soil is unable to supply moisture as rapidly as the root system of the plant can absorb it, soil moisture then becomes a limiting factor in plant growth. From the standpoint of moisture supply, a soil is satisfactory for the growth of a plant when it can supply water to the absorbing surfaces of the root system fast enough to meet the vital activities of the plant. Osmosis, which plays such an important role in the ascent of sap, plays an equally important part in the absorption of soil moisture and solutes. A very important relation is therefore set up between the density of the soil solution and the density of the sap in the roots. The osmotic concentration of the cell sap of the roots is closely correlated with the concentration of the soil solution which in turn is dependent upon the amount of moisture in the soil. Shull (*116*) has, in fact, found that roots have an osmotic concentration somewhat above that of the soil solution of a soil in which the water has been reduced to the wilting coefficient.

This suggested that for the present investigation a comparative determination of the cell sap density of leaves and roots would afford a valuable index of soil moisture content, since the frequently important variables of soil fertility

[14] The species about which there was some doubt as to their specific identity were referred to the National Herbarium for confirmation by specialists.

would be automatically eliminated.[15] Two comparisons between the density of the sap of second-year leaves of 2–2 transplants[16] of western yellow pine and that of the smaller roots of the same plants were accordingly made, one in July and the other in September. One lot of the roots was thoroughly washed in distilled water and air-dried to practically the same condition as that originally obtaining on their surface. From another lot as many as possible of the soil particles were carefully removed without washing the roots. Both lots were packed into test tubes and subjected to the same technique of freezing and pressing as the leaves. The results of the tests are given in Table XIV.

TABLE XIV.—*Comparison of sap densities in leaves and roots*

	Depression of freezing point	Osmotic pressure
	Degrees C.	*Atmospheres*
July 27, 1920:		
Leaves	1.35	16.2
Roots (washed in distilled water)	1.17	14.1
Roots (unwashed)	1.03	12.4
September 20, 1920:		
Leaves	1.48	17.8
Roots (washed in distilled water)	1.36	16.4

These data show that the density of the sap is lower in the roots than it is in the tops of the same plants.[17]

It is of interest to note that the density of the cell sap changes during the day, increasing as the day advances and decreasing toward evening. The daily minimum occurs in the early morning, indicating an apparent relation between sap concentration on the one hand and photosynthesis on the other. This suggests the observation of Bose (*7*) who has found that the effects of light and warmth are antagonistic. The former induces a retardation and the latter an acceleration of growth. In fact, in the later or higher stages of plant succession, where competition for light is intense, the plant which is photosynthetically the most efficient is most likely to survive because of its greater food supply.

This is corroborated by the results obtained in the present study. The leaf sap of three-year-old seedlings of Douglas fir growing in the Cottonwood Nursery under half shade in July gave a depression of the freezing point of 1.39° C., denoting an osmotic pressure of 16.7 atmospheres as compared with a freezing point depression of 1.59° C. and a corresponding osmotic pressure of 19.1 atmospheres in adjacent unshaded seedlings of the same age and species. In September tests on sap of the same two lots of seedlings gave very similar results. The shaded seedlings showed a freezing point depression of 1.34° C. and an osmotic pressure of 16.1 atmospheres, while the sap of the unshaded seedlings depressed the freezing point 1.50° C., indicating an osmotic pressure of 18.0 atmospheres. The herbaceous and even some of the ligneous plants growing under a dense forest canopy were also found to possess relatively low concentrations.

There is, moreover, a direct relation between growth form and sap concentration: The leaves of ligneous plants were found to have a higher osmotic concen-

[15] The recent work of Bouyoucos and his colleagues (*8–9, 10–13*), Hibbard and Harrington (*65*), and Keen (*70*) is of considerable interest in this connection.

[16] Nursery stock grown two years in the seed bed and two years in the transplant bed.

[17] This conclusion is confirmed by the results of investigations by Hannig (*44*), Hibbard and Harrington (*65*), and McCool and Millar (*90, 91*) The latter investigators have also thrown additional light on the relation between the concentration of the cell sap and environmental conditions.

tration than those of herbaceous species.[18] Variations in growth form are in turn dependent upon environmental conditions. Some species which are ordinarily trees may develop as shrubs in certain environments as, for example, the dwarfing of tree growth at timber-line in parts of the Rocky Mountains.

The existence of an osmotic gradient within the plant, which has been referred to above, is now readily demonstrable in the leaves of tall trees.[19] Determinations made in the present study showed higher concentrations in the top of the tree. The osmotic concentration of the cell sap of leaves increases from lower to higher levels in the same plant. A further study of this phase was made on the Wasatch National Forest, where the two-year-old leaves of 10 trees of western yellow pine growing in Whipple Gulch yielded the following data:

Height of leaves selected	Depression of freezing point in degrees C.	Osmotic pressure in atmospheres.
Base of trees	1.44	17.3
Top of trees (average height above ground, 40 feet)	1.54	18.5

These data afford additional proof of the soundness of the above-stated proposition. It is a general principle that conditions are more favorable to the formation of soluble carbohydrates in the upper parts of the crowns of trees. It is therefore reasonable to assume that the greater osmotic pressures are regularly developed in the tops and that smaller pressures exist at the bases of the crowns, where these substances are not commonly stored. Variations in the sugar content of the leaves due to differences in illumination would also be expected to cause material fluctuations in the osmotic concentration of the sap. These sap-density figures consistently confirm these postulates. The fact that the higher osmotic pressures occur in the tree tops is in accord with Dixon's (*23-24, 32-33*) theory that the transpiration stream is set in motion through the plant by secretory action occurring in the leaf cells or by evaporation and capillarity at their surfaces drawing water from the tracheae. The condition of saturation surrounding these cells determines which agency shall be effective. With normal transpiration unaffected by root pressure, the cohesion of the sap is sufficient to explain the transmission within tracheae of the tension downward, and the resultant ascent of the sap. With the evaporation of water through the stomata a somewhat higher concentration of the sap is produced in the cells immediately adjacent to the stomata. This upsets the osmotic equilibrium and a current of sap is set in motion, extending all the way from the soil to the stomatal cells of the topmost leaf of the tree. Dixon (*32*) has shown that the tensile strength of the sap is much in excess of the tension necessary to raise the sap to the top of the tallest trees. Further, the osmotic pressures which he has measured have always been found adequate to resist the tension caused by the transpiration stream. In many cases, however, other factors enter, such as the presence of an unusually large amount of stored soluble carbohydrates or a high concentration of the soil solution, which develop pressures greatly in excess of those required by the transpiration stream alone.

[18] The same thing has been observed by several other investigators (*20, 40, 50, 54, 56, 59, 60.*)

[19] On the basis of determinations of the osmotic concentration of the leaf sap at different levels above the ground, made by the plasmolytic method, Ewart (*38*) advanced the theory that the density of the leaf sap increases from lower to higher levels in the same plant. Further observations have been made by Dixon and Atkins (*25, 26*), and Harris, Gortner and Lawrence (*33*), who used the refined freezing-point depression method.

One of the strongest arguments in support of the theory that water intake by the plant depends on the osmotic concentration of its tissue fluids is to be found in a comparison of the saps of parasite and host. The osmotic concentration determinations on parasitic Loranthaceae in relation to those of their hosts, discussed on pages 897–898, show that osmotic pressure is one of the most important forces by which the solutes obtained by the parasite are withdrawn from the tissues of the host.

The facts just presented are regarded as fully justifying the assertion made on an earlier page that an intimate relation exists between the concentration of the cell sap and the water relations of the plant. The correlation of data on water relations is facilitated by comparative studies of sap density. Sap density may be used as a convenient measure for expressing with an accuracy sufficient for practical purposes the moisture conditions of different sites and different forest types. Such an index must not be confused with the underlying causal factors which produce it. The osmotic concentrations characteristic of species adapted to different sites serve as criteria of these sites, and, in view of the fact that all of the activities of the protoplasm must take place in the environment of the cell sap, the relative densities of the sap of a species growing under diverse conditions evidently indicate the manner in which those conditions affect the species. In short, the concentration of the cell sap is an expression of the biological requirements of a species since it indicates the ability of a plant to withdraw water from the soil.

SEASONAL VARIATION IN SAP CONCENTRATION

Table VII shows that the sap concentration for a given species varies not only from site to site but on the same site from season to season. The September concentrations were in general considerably lower than those found in July, a fact which is directly related to the influence of the environment upon the plant. Dixon and Atkins (*35*) have pointed out that since the major part of the osmotic pressure in the cell sap of plants is due to dissolved carbohydrates, it is evident that the variations in the sap density are largely due to fluctuations in the synthesized solute content of the cells. These differences, therefore, are dependent not only upon the moisture content of the soil but also upon atmospheric conditions which may materially influence current sap concentrations through their effects upon the photosynthetic activities of the plant and the production of carbohydrates. In the course of a year the plant passes through a definite cycle of changes directly dependent upon these varying conditions.

A number of factors combine to start growth in the early spring. The soil is abundantly supplied with water; the snow is melting under the influence of rising temperatures and spring rains; the intensity and duration of the sunshine are increasing; and yet transpiration is still moderate. All of these conditions favor the maintenance of a low sap density. With the advance of the season and the advent of midsummer the supply of available soil moisture is usually much depleted, as has been shown, and the rate of water loss from the plant through transpiration has been materially increased by the occurrence of the highest temperatures of the season and the greatest intensities of sunlight. Summer is, furthermore, the season of minimum rainfall. All these factors unite to produce the maximum sap densities of the growing season. It is during this period that death from drought most frequently occurs. To survive, a species must be able to adapt itself to the changing conditions and to resist the adverse stresses. It can do this by a reduction of transpiration or by such an increase of sap density that absorption continues even in spite of an increasingly concentrated soil

solution.[20] Species unable to thus adapt themselves will disappear from the type. As autumn approaches with its lower temperatures and reduced transpiration the fall rains augment the moisture supply. With the return of these favorable conditions the density of the cell sap is again materially lowered. The September determinations were made after the occurrence of several fall rains, of which the results are apparent in the prevailingly low densities compared with those of July.

While winter is the dormant season for growth and, in the main, for photosynthesis also, transpiration continues except during such times as the leaves are actually frozen. In winter the water losses of coniferous evergreen trees with their leaves intact have been shown by Weaver and Mogensen (*120*) to be relatively no greater than the losses from deciduous trees after leaf-fall. This indicates great water-retaining capacity in the leaves of conifers, many of which are very hardy. With some species, at least, a small amount of photosynthesis doubtless occurs on some of the warmest days, but it is necessarily of short duration.

TABLE XV.—*Sap densities in first and second year leaves of conifers*

Species	Depression of freezing point in degrees C.		Osmotic pressure in atmospheres	
	First-year leaves	Second-year leaves	First-year leaves	Second-year leaves
Pinus ponderosa	1.03	1.11	12.4	13.4
Pinus ponderosa scopulorum	1.35	1.38	16.2	16.6
Pinus flexilis	0.91	1.29	11.0	15.5
Do	0.62	0.79	7.5	9.5
Do	0.51	0.54	6.1	6.5
Do	0.64	0.67	7.7	8.1
Pinus sylvestris	1.17	1.25	14.1	15.0
Do	0.66	0.75	8.0	9.0
Pinus austriaca	0.81	1.19	9.8	14.3
Pseudotsuga taxifolia	0.64	0.66	7.7	8.0
Do	0.76	0.92	9.2	11.1
Abies concolor	0.70	0.83	8.4	10.0
Do	1.02	1.35	12.3	16.2
Do	1.18	1.28	14.2	15.4
Do	1.39	1.47	16.7	17.7
Do	0.96	1.04	11.6	12.5
Do	0.57	1.06	6.9	12.8
Do	0.54	0.64	6.5	7.7
Abies lasiocarpa	0.75	0.86	9.0	10.4
Do	1.20	1.35	14.4	16.2
Do	1.21	1.30	14.6	15.6
Do	0.8	0.85	9.8	10.2
Do	0.85	1.12	10.2	13.5
Do	0.60	0.74	7.2	8.9
Picea parryana	0.80	1.02	9.6	12.3
Do	1.21	1.34	14.6	16.1
Do	1.09	1.40	13.1	16.8
Do	1.05	1.16	12.6	14.0
Picea engelmanni	1.17	1.29	14.1	15.5
Do	1.19	1.40	14.3	16.8
Do	0.86	0.95	10.4	11.4
Picea excelsa	0.86	1.00	10.4	12.0

The December and January collections were made while the leaves of the conifers and evergreen shrubs were frozen solid; the temperatures varying from 5° to 15° C. below the freezing point. These winter determinations were found to be at variance with the summer and autumn series in that the conifers showed low concentration, while the closely associated evergreen shrubs exhibited high concentration. Furthermore, the sap densities of the shrubs increased with increase in elevation, a complete reversal of the results secured in the series

[20] The increasing physical grip of the soil particles on the soil solution may also be important.

of the preceding July and September. Inasmuch as these results were so completely at variance with the other two series a special study was made to determine the underlying causes. The results of this investigation are incorporated in the subsequent discussion of "Seasonal Changes in Food Reserves."[21]

It has been shown that young, newly developed leaves have uniformly lower sap densities in July than one-year-old leaves. In all cases the first and second year leaves were taken from the same twigs. In September the relative densities were found to be variable; about one-half of the species showed higher densities in the leaves of the current year and half in those of the second year. By December and January, however, all of the species tested showed uniformly higher densities in their second-year leaves, as shown in Table XV.

These data are in general agreement with the preceding discussion and also with that which is presented in the next section. This difference in density of the sap of the first and second year leaves is possibly due to the greater amount of dissolved carbohydrates in the second-year leaves with resultant higher sap densities.

Another interesting relation was noted in September between yellow and red leaves and normal green ones on the same branches of aspen, large-tooth maple, and chokecherry. The results obtained in Big Cottonwood Canyon are given in Table XVI.

The leaves on these deciduous broad-leaved species were just beginning to take on their gorgeous autumnal colorations. It is probable that in the case of the colored leaves the abscission layer was forming at the base of the petiole and that the greater part of the carbohydrates had already passed from the leaves to the storage organs. This offers a possible explanation for the lower densities in the sap of the colored leaves taken from the same branches as the green leaves.

TABLE XVI.—*Sap density as influenced by autumnal color change*

Species	Depression of freezing point	Osmotic pressure
	Degrees C.	*Atmospheres*
Populus tremuloides:		
Yellow leaves	1.39	16.7
Green leaves	1.83	22.0
Acer grandidentatum:		
Red leaves	1.44	17.3
Green leaves	1.52	18.3
Prunus melanocarpa:		
Red and yellow leaves	1.28	15.4
Green leaves	1.75	21.0

It is obvious that the concentration of the sap of any species is subject to wide variations. This is, nevertheless, of great significance in showing that the striking variations in the cell sap concentration of a given species encountered in different seasons and on different sites serve to emphasize the necessity of having a large number of determinations available for the same species on different sites and at different seasons of the year before attempting a correlation of the osmotic concentration of the cell sap with plant activities, dynamically exemplified in growth, distribution, and succession.

[21] It is of interest to note in passing that Lewis and Tuttle (*80*) found that the maximum sap concentrations are reached in the leaves of *Picea canadensis*, *Pyrola rotundifolia*, and *Linnaea borealis* in the winter, and that the variations are due chiefly to the nonelectrolytes of the sap, the sugar content variation of which followed closely the fluctuations in the sap concentration.

SEASONAL CHANGES IN FOOD RESERVES

The low osmotic concentrations of the conifers and the high concentrations found in the evergreen shrubs in the middle of the winter show a strong tendency toward a complete reversal of the results of the summer and autumn determinations. This was especially noticeable in the Taylor Canyon series. Douglas fir, white fir, alpine fir, and limber pine showed unusually low densities, while the two junipers were abnormally high. The evergreen shrubs, *Artemisia tridentata*, *Cercocarpus ledifolius*, *Odostemon repens*, *Pachystima myrsinites* and *Ceanothus velutinus*, showed strikingly high winter sap densities which increased with an increase in elevation. These results were confusing until micro-chemical tests for starch and oil were made on five conifers, Douglas fir, alpine fir, white fir, limber pine, and Rocky Mountain juniper, and the above five evergreen shrubs. The conifers gave a strong oil reaction indicating the presence of large amounts of oil and fatty substances in the leaves, while the evergreen shrubs gave only faint oil reactions with the common osmic-acid tests.[22] No substantial increase in the oil content of the evergreen shrubs was observed during the winter.

Starch was not detected in any of the conifers or evergreen shrubs, in either January or February, when treated with an aqueous solution of potassium iodide and iodine (*98, p. 28*). With the rise of the sap in the spring strong starch reactions were obtained even without preliminary swelling of the starch grains with potassium hydroxid. These tests led to the conclusion that with the advent of cold weather in the autumn and early winter a large part of the starch in the conifers is converted into oil or fatty substances which are osmotically inactive and form emulsions having low osmotic concentrations. In the evergreen shrubs which showed little or no oil present the starch was evidently converted into soluble sugars, thereby materially increasing the osmotic concentration of the cell sap.[23] In the late winter or early spring a reconversion of starch and an apparent decrease in the amount of oil occurs throughout the tissues of the stem. This converted starch is apparently consumed in the formation of the spring growth, and it is not until summer that a fresh supply begins to be deposited.

Starch, when found during the winter, was most abundant in regions remote from centers of conduction and in cells with thin or unlignified walls or large

[22] The definite increases noted in these observations on the conifers accord with those of Fischer (*39*), Preston and Phillips (*105*), and Sinnott (*117*), who have listed the majority of the conifers of eastern North America among their "fat trees."

[23] These conclusions are in general agreement with the findings of Fisher (*39*), LeClerc du Sablon (*78*), Niklewski (*96*), Preston and Phillips (*105*), Sinnott (*117*), Mer (*92*), Mitra (*94*), Miyake (*95*), Tuttle (*118*), (*119*), Coville (*22*), Petersen (*100*) and others who have discovered many important facts in regard to the character and seasonal changes of the food reserves in woody plants. Fisher (*39*), Niklewski (*96*), and LeClerc du Sablon (*78*) found that the amount of sugar varies during the year. Lidforss (*81–82*) found that with most of the wintergreen plants of South Sweden, during cold weather at least, the starch is almost entirely changed to sugar, although on the return of warm weather starch may be again deposited in the cells. Mitra (*94*) determined that the maximum starch content in apple stems and roots is reached in October and November and that the total sugars increased in January and March. Rigg (*107*) also has observed the accumulation of sugar at the expense of starch, during the winter, in the evergreen angiosperms of the Puget Sound Region. It is important to note that Coville (*22*) found that the exposure of plants to cold results in the transformation of stored starch to sugar, with the consequent development of high osmotic pressures. He advances the theory that, during the process of chilling, the starch grains stored in the cells of the plant are at first separated by the living active cell membranes from the enzyme that would convert the starch into sugar, but that when the plant is chilled the vital activity of the cell membrane is so weakened that the enzyme permeates it, comes in contact with the starch and transforms it into sugar. Sinnott (*117*) suggests that the ease with which water or substances soluble in water have access to the plant cell is probably a determining factor in the extent to which starch is changed to sugar, and that differences in the type of food reserve may be due to differences in water content of the various storage cells, resulting in enzyme activity, or differences in the ease with which enzymes have effective access to the storage cells.

pits. However, it is evident that non-nitrogenous materials are most commonly stored in the form of starch and frequently this is partially or wholly replaced during the winter by sugar or fats. A sudden increase in temperature during the winter or early spring causes a reformation of starch. Under favorable conditions this may occur more than once in the course of a single winter.[24] There is furthermore, a distinct advantage in the economy of the plant in producing, from the same nutrient material, substances of higher or lower osmotic concentration according to the character which metabolism assumes.[25]

The supply of reserve food is an important factor in the inception of early spring growth. The reserve food materials stored up in the autumn are probably largely utilized in leaf and also in blossom formation, when the latter precedes leaf formation. Growth does not begin simultaneously in the evergreen and deciduous trees of the Intermountain Region. It would appear reasonable to assume that diameter growth proper, as distinguished from any preliminary swelling of the tissues, may be delayed in the deciduous trees until the new leaves have developed and have become sufficiently active photosynthetically to supply the requirements of rapid cell formation. Evergreen conifers, on the other hand, have an adequate amount of living leaf tissue to supply the requisite materials for growth as soon as growing temperatures are reached in the spring. But, even in conifers, the stored food materials are principally, if not wholly, consumed in the incipient stages of the current growth while growth during the main part of the growing season is largely influenced by other environmental factors, notably precipitation, since this is the chief determinant of the moisture supply in this region (*75, 76*).

Since winter sap densities are materially altered by transformations in the food reserves, any determinations which are made during the winter must be interpreted accordingly. For example, higher winter sap concentrations should not be interpreted as necessarily indicating greater drought resistance in one species than in another. Because of the material changes in the food reserves following the advent of cold weather it would appear inadvisable to use winter determinations alone in a correlation of sap density with environmental conditions. In the Intermountain Region, at least, the dry part of the growing season is the most critical from the standpoint of plant distribution and succession. Sap densities common to this period are therefore of greater significance than those of winter for correlation with the phenomena, which are largely dependent upon environmental conditions.

SAP DENSITY IN RELATION TO FOREST DISTRIBUTION AND PLANT SUCCESSION

The sap density of any single species shows variations corresponding to the degree of xerophytism of the forest types or associations in which that species is growing, especially when the determinations are made at or near the critically dry part of the growing season. Although a plant with low sap concentration can procure the necessary water from soil having a high moisture content, the total amount of available soil moisture is not always in itself the limiting factor in the struggle of a seedling to become established. Its success often depends principally on its ability to exert, through the concentration of the cell sap, an osmotic pressure sufficient to absorb water from the soil and at the same

[24] These observations have been confirmed by Mer (*92*).

[25] Pfeffer (*102, p. 134–147*) has pointed out that reserve food materials may be stored up in an insoluble form as starch, oil or proteid without causing any increase in the osmotic concentration of the cell sap, but that even the concentration of two molecules of a monosaccharide to one of a disaccharide may result in reducing the osmotic concentration by one-half.

time maintain an economically efficient transpiration rate under temperature conditions favorable to photosynthesis. This dual relation between absorption and transpiration, then, is more often the determining factor in the composition of the stand than absorption alone. It is to this that the several forest types are due.

Evidently, therefore, (*a*) the water relations of the plant have a vital bearing on the succession of plant associations and (*b*) the causes of these phenomena are associated with the osmotic properties of the plant juices and the soil solution. The densities of the sap of all species tested in the main Wasatch Mountains, which are averaged by types, growth forms and seasons in Table X, illustrate this point. The average densities of the sap of all species tested in each type in the Ephraim Canyon series in July, 1921, are given in Table XVII.

TABLE XVII.—*Average sap densities by types for the Ephraim Canyon series*

Type	Depression of freezing point	Osmotic pressure
	Degrees C.	*Atmospheres*
Greasewood-shadscale	4.29	51.4
Sagebrush	2.35	28.2
Pinon-juniper	1.78	21.4
Oak brush:		
South aspect	1.66	20.0
North aspect	1.36	16.4
Average	1.47	17.7
Aspen-fir	1.25	15.0
Spruce-fir:		
South aspect	1.25	15.0
North aspect	1.05	12.6
Average	1.16	14.0

These averages, together with the principal climatic factors, are plotted in figure 5, which further emphasizes the correlation between site and sap density. The sap of sagebrush, the extreme range of which covers several types, shows the same characteristic decrease in density with an increase in altitude. (Fig. 5.) A comparison of the opposite north and south aspects at the same elevations in the oak brush and spruce-fir types also shows a decrease in sap density corresponding with an improvement in site conditions. The plants have the lower densities on the northern aspects, which in these two cases are the more favorable for plant growth. Similar comparisons can also be drawn from the majority of the species listed. The common progressive succession is from the high osmotic pressures in the drought-resistant species of the pinon-juniper and chaparral zones of the lower mountains, through the western yellow pine, aspen-fir, and logdepole pine types composed of species having successively lower sap concentrations, to the climax spruce-fir type of uniformly low osmotic pressures. The establishment of a forest cover is conducive to greater stability and the development of progressively lower osmotic concentrations in the perennial species. It is somewhat different in the case of annual herbs which are capable of completing their life cycle in shorter periods, often during a rainy season when conditions are optimum for vegetative growth.

A correlation of plant succession with the underlying casual factors shows that the succession is from drought-resistant species toward species of less drought resistance as the atmospheric and soil moisture increases and produces greater stability and lower sap densities. It is evident that the existence of a high osmotic concentration of the soil solution tending toward physiological dryness of the soil would prove most detrimental to species of low sap concentration by cutting off the moisture supply. Shallow-rooted species having

low sap concentrations would be the first to be adversely affected by periodic droughts. The depth of penetration, lateral spread, general character of the root system and volume of soil penetrated by the roots, as well as the capacity of the species to absorb moisture, are all important in determining the adaptability of the species to a given site. These factors also influence the amount of moisture available to the plant.

The cutting off of the supply of available soil moisture through freezing of the soil is occasionally a limiting factor. Although the Wasatch Mountains are usually covered during the winter by a mantle of snow often several feet deep, under which the soil is seldom frozen, windswept ridges and southwestern aspects are intermittently bare of snow for sufficient intervals to permit freezing to considerable depths. Deep freezing of the soil, especially when accompanied by high winter evaporation stresses, is the chief factor accountable for the limited number of native species found on these sites. The vegetative cover is generally composed of a few species having deep taproots which extend below the depth to which the soil freezes. The freezing of the soil accompanied by high evaporation and consequent excessive transpiration tends to exclude coniferous species and others having low sap concentrations. Adverse factors would naturally be more markedly inimical to the establishment and growth of the young seedlings than to the growth of those plants which have already become established and it is the conditions influencing reproduction which ultimately determine the composition of a given forest type or association.

The zonation of plant associations and their alternation on opposing north and south aspects can be logically explained on the basis of the effect of environmental conditions on the known physical properties of the cell sap of their component species. Although other factors, such as shade or other means of protection, may cause more or less sporadic occurrences, it will usually be found that they do so through mitigating the environmental conditions during the seedling and sapling stages.

A discussion of sap density in relation to forest distribution and plant succession would not be complete without considering its practical application. Foresters have long recognized that the denudation of an area bearing a certain type of vegetation may be followed by an entirely different type of cover; for example, aspen often temporarily replaces Douglas fir and Engelmann spruce after their removal by burning. Douglas fir is frequently followed by lodgepole pine on burns. To a less extent silvicultural management cuttings are followed by a natural succession, as shown by Bates (*4*) and Weidman (*121*). When a mixed stand of Douglas fir, western larch (*Larix occidentalis*), grand fir (*Abies grandis*), and Engelmann spruce is cut over under certain conditions, the first reproduction which appears is sometimes almost exclusively the inferior grand fir, the more valuable species coming in again only after a considerable lapse of time. In order to control the succession in such cases, the forester must use to advantage the known laws governing plant succession, adapting his silvicultural practice to them. The main available means of doing this is by adapting the degree or method of cutting to the particular case. In some stands, for example, it might be economically desirable to retain the present condition, which may not be the ultimate climax stage; in others the natural succession might be hastened; in still others it may be desirable, if possible, to retard it. The maintenance of a particular composition or density will depend upon a knowledge of the competition and reaction of the dominant species and the individual trees in the stand, and the relation of these to the successional development. In determining what species will permanently occupy any given site the conditions must be known which will induce the minimum moisture supply and the maximum osmotic concentration likely to be developed in any climatic cycle.

Sap density also vitally affects the success of artificial reforestation in regions of deficient and poorly distributed rainfall. Only those species can succeed which can maintain a sap concentration high enough to provide an osmotic gradient sufficient to maintain the transpiration stream. In other words, the plant must be able to absorb moisture from the soil to replace the water lost through evaporation from the leaves. It would, therefore, appear unwise to attempt to grow on any site a species having a smaller range in sap concentration than that exhibited by native species normally present on the site; otherwise the introduced species will be unable to succeed in its new environment.

GROWTH AND REPRODUCTION IN RELATION TO SAP DENSITY

Osmotic pressure may exert a decided influence on the growth and reproduction of plants. Livingston (*83*) has shown that growth is accelerated in weak soil solutions and is retarded in concentrated ones. Reproduction in some cases appears to be almost entirely dependent upon the osmotic pressure of the soil solution surrounding the roots. The density of the sap increases as the season advances due largely to the accumulation of solutes, although there is some evidence that diminished absorption of moisture from the soil is partially responsible for the increase of sap density. Reed (*106*) has found that the growth and sap concentration in young trees vary in opposite directions; that is, low concentrations of the sap in the shoot appeared to be associated with abundant water intake and rapid vegetative growth, while higher concentrations were associated with slow growth and bud formation.

It was found in the present investigation that both age and the conditions of growth exercise a profound influence on the osmotic pressure of the cell sap. Newly developed leaves of the two varieties of western yellow pine, lodgepole pine, and western white pine showed lower concentrations in July than one-year-old leaves taken from the same plants, all of which were growing in the Cottonwood Nursery under identical exposure. The results are given in Table XVIII.

TABLE XVIII.—*Effect of maturity on sap density in pine leaves*

Species, and age of leaves	Depression of freezing point	Osmotic pressure
	Degrees C	*Atmospheres*
Pinus ponderosa:		
Month-old leaves	1.39	16.7
Year-old leaves	1.55	18.6
Pinus ponderosa scopulorum:		
Month-old leaves	1.46	17.6
Year-old leaves	1.57	18.9
Pinus contorta:		
Month-old leaves	1.29	15.5
Year-old leaves	1.42	17.1
Pinus monticola:		
Month-old leaves	1.07	12.9
Year-old leaves	1.41	17.0

The young succulent leaves, when subjected to the regular technique in expressing the sap, yielded three to four times the quantity that was secured from the same amount of mature leaves under the same pressure. The sap of the young leaves was also thin and almost colorless, resembling a sugar solution and largely lacking the characteristic resinous odor of coniferous leaves, while the sap from the mature leaves was thicker, possessed the resinous odor, and was of a bright green color due to the presence of some of the chlorophyl matter which was expressed with the sap.

It is evident not only that periods of retarded growth correspond to periods of high sap concentration but also that in trees found typically in regions of little

moisture, as, for example, the juniper and western yellow pine types, a slower rate of growth and abnormally high osmotic pressures are concomitant. A low concentration of the soil solution would in turn favor selective absorption through the action of the osmotic gradient and still permit the maintenance of a relatively low sap concentration in the leaves of the plant desirable from the standpoint of stimulating rapid growth.[35] Forest trees of course make their best growth on the best sites, the sites from the best to the poorest being merely a relative classification of the growth capacity of different habitats as influenced by environmental factors. The lowest sap concentrations for a given species are found on those sites on which the environmental conditions are most favorable for rapid growth.

The intimate relation which exists between sap density and growth rate is emphasized in the present study. The growth rate of Douglas fir and white fir in Big Cottonwood Canyon is more rapid on the south aspect than on the opposite north aspect at an elevation of 7,500 feet where the aspen-fir type meets the chaparral type. The competition of the open stand of trees on the south slope is in this case nowhere intense, either with one another or with the shrubby species. The trees are rooted in a soil layer below that of the bulk of the shrubs; one in which the soil moisture supply is abundant, as evidenced by the presence of aspen, an indicator of an ample supply of subterranean moisture. On the north aspect, on the other hand, growth is retarded by competition for the soil moisture in the lower soil layers, not only between individuals in a denser stand of forest trees, but also between the trees and the dense stand of deeply rooted shrubs. Higher sap concentrations are also encountered on this north aspect. The south aspect is a striking example of a low sap concentration of Douglas fir and white fir associated with a relatively high transpiration rate. This can be fully explained by the presence of an abundant supply of subterranean moisture. The correlation of a low sap density with this rapid growth rate of well established sizeable trees should not be confused with the question of favorableness or unfavorableness of site from the standpoint of the establishment of reproduction. Practically no seedlings of either species are being established on the south aspect on account of the meagerness of the moisture in the upper foot of soil and the excessive evaporation, while on the north aspect with its favorable moisture conditions near the surface there is found an abundance of advance reproduction.

A somewhat similar comparison can be drawn in the case of the spruce-fir type. A study of Table VII shows that the density of the cell sap increases as timber line is approached on ridge tops and south aspects above 10,000 feet in elevation. With this increase in sap density a falling off in rate of growth is also apparent in Engelmann spruce, alpine fir, and limber pine on these sites.

INFLUENCE OF STRUCTURAL AND PHYSIOLOGICAL FACTORS

The structure of most plants varies with the site and even with the fluctuating environmental factors of the same site. The leaf, because it is the seat of important physiological activities of the plant and because of its modification by external factors, has long been the field for numerous investigations. The majority of such studies have been confined to the morphology and histology of the leaf, independent of its relations to environmental factors. In contrast to these Clements (*19*), Hanson (*45*), and Sampson and Allen (*112*) took into account measured physical factors in relation to leaf structure. The importance of this relationship was repeatedly emphasized in the present study while collecting the

[35] According to Hoagland (*66*) marked absorption of nutrient materials may take place during all stages of growth when suitable concentrations of the various ions are maintained. Burd (*14*) has pointed out that for many plants high concentrations of the soil solution at certain stages of growth are probably undesirable.

leaf material for the sap density determinations. Plants on exposed sites are usually thicker, more hairy, have a more highly cutinized and thicker epidermal wall, a more compact palisade parenchyma, and more closely crowded stomata than on less severe sites.

The powers of accommodation or adaptation exhibited by plants are evident in the density of the sap. The extent of adaptation varies with the plasticity of the species. The curl-leaf mahogany (*Cercocarpus ledifolius*), manzanita (*Arctostaphylos pungens*) and mountain myrtle (*Pachystima myrsinites*), which have thick leathery leaves, and *Ceanothus velutinus*, with a very sticky leaf, are species possessing variable sap concentrations. On the other hand, the succulent *Opuntia* and *Sedum* have surprisingly low sap densities. Those plants which possess a low transpiration rate as a result of anatomical modifications, the presence of pubescence or pulverulence, and those plants having pronounced water storage tissue in succulent leaves or stems are capable of maintaining surprisingly low concentrations of the cell sap.

In many plants the major physiological activities, such as photosynthesis, absorption, and transpiration, are materially modified by special protective coverings and by anatomical and even functional adaptations. The rate of transpiration, for example, may be materially reduced by structural modifications. Since osmotic phenomena are so intimately connected with all these vital physiological functions it is clear that an intimate relation also exists between structural adaptations and the density of the cell sap.

Our knowledge of the water relations of some western mistletoes also has been augmented by a study of the osmotic concentration of the sap of these parasites in comparison with that of their hosts. Determinations on the sap of *Razoumofskya douglasii* on Douglas fir in Big Cottonwood Canyon and *R. americana* on lodgepole pine on Beaver Creek, both made in September, 1920, and *R. cryptopoda* on western yellow pine and *Phoradendron juniperium* on one-seed juniper (*Juniperus monosperma*), in August, 1921, at the Fort Valley Forest Experiment Station near Flagstaff, Arizona, are given in Table XIX.

TABLE XIX.—*Sap densities of some western mistletoes and their hosts*

Species	Depression of freezing point.	Osmotic pressure.
	Degrees C.	*Atmospheres*
Razoumofskya douglasii	1.64	19.7
On *Pseudotsuga taxifolia*	0.96	11.5
Razoumofskya americana	1.52	18.3
On *Pinus contorta*	1.41	17.0
Razoumofskya cryptopoda	1.46	17.6
On *Pinus ponderosa scopulorum*	1.42	17.1
Phoradendron juniperium	1.30	15.6
On *Juniperus monosperma*	1.28	15.4

These results indicate that the osmotic density of the sap extracted from the tissues of the parasite is generally greater than that from the mature leaves of the host.[27] A higher osmotic concentration of the sap of the parasite is not a necessary condition for the temporary success of the parasite. The parasite should be able to draw from the relatively dilute solutions in the stem of its host in competition with organs of actually higher osmotic density, except at periods when the supply of available moisture is limited, just as young leaves are able to draw water in competition with old leaves of high osmotic density. The Arizona

[27] The studies of Harris (*58*) on desert Loranthaceae and those of Harris and Lawrence (*49*) on the parasitic Loranthaceae of Jamaica accord with the above findings.

tests were made during a period of unusually wet weather, which probably accounts for the small differential between the sap of the parasite and that of the host. Again, osmotic pressure has been found to be one of the fundamental variables among the forces by which solutes are drawn from the tissues of the host, a discovery that has contributed to the knowledge of the physiology of parasitism.

In the preceding pages the great importance of knowing the reactions between the environmental factors and the various physiological functions of the plant have been repeatedly emphasized. The variable results noted in the winter sap density studies could not have been properly interpreted without an examination of the starch content of the leaves. It has been shown that, through the osmotic concentration of the sap, the initial changes preliminary to early spring growth may be detected by the rise and consequent effect on the density of the sap in the leaves of evergreens. The seasonal changes in carbohydrate conversion may also be followed by making use of the osmotic pressure method. Of no small significance is the applicability of the method to the study of the water balance of the plant—changes in its water relations due to moisture supply and water loss.[28]

The fact has been repeatedly emphasized during this investigation that no one factor or group of factors should be singled out, to the exclusion of all others, as an explanation of all physiological phenomena, and furthermore, that the normal physiological activities of the plant can only be interpreted when they are properly correlated with both the climatic and soil conditions of the environment.

RELATION OF DENSITY OF SAP TO HARDINESS

The intimate relation of cell sap concentration to drought resistance has already been brought out. There is also an apparent relation to winter hardiness. This has been indicated by a number of investigators who have correlated the transformation of starch into sugar and the resultant increase in the density of the cell sap in the winter with frost resistance. Lidforss (*81*, *82*) and Petersen (*100*) have shown that a close relation exists between the sugar contents and frost hardiness; the more sugar the less injury from frost. The sugar is believed to protect the living protoplasm against frost injury by lowering the freezing point of the cell contents.[29]

Numerous theories [30] have been advanced concerning the mechanics of frost injury, such as failure of the protoplasm to regain water lost when ice crystals form in the tissues, the precipitation of proteins, or other metabolic changes accompanying low temperature. A number of empirical observations in the Intermountain Region indicate that the injurious effects come when ice crystals form. Wet shoots freeze at a higher temperature than dry shoots. Wet leaves show more serious injury at a given temperature than dry leaves. A period of cold weather immediately following a rain or wet snow is thus more dangerous than a period of cold dry weather. With the approach of spring there occurs an increase in the tenderness of buds.[31]

[28] Bates and Zon (*5*) have pointed out that the termination of the season's photosynthetic activity may possibly be determined by the same method.

[29] Fischer (*39*), Le Clerc du Sablon (*76*), and Niklewski (*96*) have also found that, while the amount of sugar in the stem varies during the year, the maximum of sugar in winter makes for greater frost hardiness.

[30] A number of these theories are reviewed and a bibliography of 50 citations dealing with the hardening process in plants is given by Harvey (*62*).

[31] These observations are in accord with the experimental results obtained by Harvey (*62*, *63*), Chandler (*17*, *18*), Rosa (*109*), Hauch and Ravn (*64*), Harris and Popenoe (*51*), and Ohlweiler (*97*). On the other hand, Salmon and Fleming (*111*) maintain that turgidity of the tissue as influenced by physiological drought appears to have more influence than sap density on the ability of a plant to resist winter killing.

The young succulent shoots and leaves are much more susceptible to early fall frosts which occur before the process of lignification has been completed. Late spring frosts after the buds have begun to swell are also very injurious and are increasingly harmful as the new leaves and shoots develop. The greater susceptibility of Douglas fir to frost injury than western yellow pine is probably ascribable to the lower temperature at which Douglas fir, as compared with the pine, reconverts the stored sugars into starch in the spring. As pointed out above, this conversion results in lower sap concentrations, which also offers a possible explanation of the relatively greater susceptibility to frost of the true firs than of Engelmann spruce (*74*).

On the whole, our native trees and shrubs are so intimately adjusted to the environmental conditions to which they have been long subjected that they are well protected from injury by ordinary freezing. On the other hand, many of the species introduced from regions with different environmental conditions are only imperfectly adapted to withstand the local conditions. They frequently grow at times when the native species, through adjustment and adaptation, have become dormant. As a result they suffer severe injury. For example, hardwood species such as green ash, box elder, black locust, and Russian olive have been completely killed by frost at times when the native conifers remained uninjured.

It is probable, therefore, that the amount of sugars present in the leaf, and consequently the density of the cell sap, has a bearing on frost hardiness. Furthermore, it is likely that the different species convert starch to sugars at different temperatures. By experimentally determining the relative temperatures at which this conversion occurs in the different species, a further guide should become available for determining their relative frost resistance and their suitability for planting on sites subject to early fall and late spring frosts.

SUMMARY

The investigation of the density of the cell sap of a large number of plants common to the important forest types of the Wasatch Mountains has yielded results of direct application in forest research. It shows that sap density may be used as an index of site in correlating the great complex of environmental factors with the physiological responses of the plant.

The concentration of the sap of a species is not constant. It may be influenced by any of the environmental conditions affecting transpiration, the products of photosynthesis, or the supply of available soil moisture. Osmotic pressure in plants is more rapidly changed by fluctuations in the moisture conditions of the site than by temperature or light.

Because of the wide range of sites covered in this investigation and the general agreement with the results of studies by other investigators, the following biological principles have been confirmed:

1. Annual herbaceous plants which complete their life cycle before the critically dry part of the growing season, and are therefore not subject to drought conditions, have low sap densities.

2. The concentration of the sap of woody species is much higher than that of herbaceous species.

3. During the growing season the lowest sap densities occur in those forest types which are well supplied with available moisture, whose plants are best adapted to secure it, and in which the complex of conditions is most favorable to plant growth. On the other hand, the highest densities occur on the most adverse (dry or saline) sites.

4. In the winter considerable variation in sap density is encountered, amounting in some cases to complete reversals of the densities of the growing season, due to changes in the soluble contents of the plant cells. In the case of evergreen shrubs, the conversion of starch to sugars materially increases the density of the sap.

5. A thick leaf having a compact structure with a thick epidermis and cuticle tends toward a lower sap concentration through its reduction of water loss from the leaf. The presence of epidermal coverings and hairs on the leaves also makes for lower sap densities.

6. Greater sap densities are generally found in the more drought-resistant species.

LITERATURE CITED

(1) ALTER, J. C.
1919. NORMAL PRECIPITATION IN UTAH. U. S. Dept. Agr. Weather Bur., Mo. Weather Rev. 47: 633–636, illus.

(2) ———
1921. WESTERN UTAH. U. S. Dept. Agr. Weather Bur. Summary Climat. Data U. S., Reprint, Sect. 11, 30 p., illus.

(3) BATES, C. G., NOTESTEIN, F. B., and KEPLINGER, P.
1914. CLIMATIC CHARACTERISTICS OF FOREST TYPES IN THE CENTRAL ROCKY MOUNTAINS. Proc. Soc. Amer. Foresters 9: 78–94.

(4) ———
1917. FOREST SUCCESSION IN THE CENTRAL ROCKY MOUNTAINS. Jour. Forest. 15: 587–592.

(5) ——— and ZON, R.
1922. RESEARCH METHODS IN THE STUDY OF FOREST ENVIRONMENT. U. S. Dept. Agr. Bul. 1059, 209 p., illus.

(6) BECKMANN, E.
1888. UEBER DIE METHODE DER MOLEKULARGEWICHTSBESTIMMUNG DURCH GEFRIERPUNKTSERNIEDRIGUNG. Ztschr. Phys. Chem. 2: 638–645.

(7) BOSE, J. C.
1918. LIFE MOVEMENTS IN PLANTS. Trans. Bose Research Inst., v. 1, 251 p., illus.

(8) BOUYOUCOS, G. J., and MCCOOL, M. M.
1915. THE FREEZING-POINT METHOD AS A NEW MEANS OF MEASURING THE CONCENTRATION OT THE SOIL SOLUTION DIRECTLY IN THE SOIL. Mich. Agr. Exp. Sta. Tech. Bul. 24, 44 p., illus.

(9) ——— ———
1916. FURTHER STUDIES ON THE FREEZING POINT LOWERING OF SOILS. Mich. Agr. Exp. Sta. Tech. Bul. 31, 51 p., illus.

(10) ———
1916. THE FREEZING-POINT METHOD AS A NEW MEANS OF DETERMINING THE NATURE OF ACIDITY AND LIME REQUIREMENT OF SOILS. Mich. Agr. Exp. Sta. Tech. Bul. 27, 56 p., illus.

(11) ———
1917. CLASSIFICATION AND MEASUREMENT OF THE DIFFERENT FORMS OF WATER IN THE SOIL BY MEANS OF THE DILATOMETER METHOD. Mich. Agr. Exp. Sta. Tech. Bul. 36, 48 p., illus.

(12) ——— and LAUDEMAN, W. A.
1917. THE FREEZING-POINT METHOD AS A NEW MEANS OF STUDYING VELOCITY OF REACTION BETWEEN SOILS AND CHEMICAL AGENTS AND BEHAVIOR OF EQUILIBRIUM. Mich. Agr. Exp. Sta. Tech. Bul. 37, 32 p.

(13) Bouyoucos, G. J.
1919. RATE AND EXTENT OF SOLUBILITY OF SOILS UNDER DIFFERENT TREATMENTS AND CONDITIONS. Mich. Agr. Exp. Sta. Tech. Bul. 44, 49 p., illus.

(14) Burd, J. S.
1919. RATE OF ABSORPTION OF SOIL CONSTITUENTS AT SUCCESSIVE STAGES OF PLANT GROWTH. Jour. Agr. Research 18: 51–72.

(15) Butler, B. S., and Loughlin, G. F.
1916. A RECONNAISSANCE OF THE COTTONWOOD-AMERICAN FORK MINING REGION, UTAH. U. S. Geol. Surv. Bul. 620: 165–226, illus.

(16) Cavara, F.
1905. RISULTATI DI UNA SERIE DI RICERCHE CRIOSCOPICHE SUI VEGETALI. Contrib. Biol. Veg. R. Ist. Bot. Palermo 4: 41–80, illus.

(17) Chandler, W. H.
1913. THE KILLING OF PLANT TISSUES BY LOW TEMPERATURE. Mo. Agr. Exp. Sta. Research Bul. 8: 143–309, illus.

(18) ———
1914. SAP STUDIES WITH HORTICULTURAL PLANTS. Mo. Agr. Exp. Sta. Research Bul. 14: 489–552, illus.

(19) Clements, E. S.
1905. THE RELATION OF LEAF STRUCTURE TO PHYSICAL FACTORS. Trans. Amer. Micros. Soc. 26: 19–102, illus.

(20) Clements, F. E.
1916. PLANT SUCCESSION; AN ANALYSIS OF THE DEVELOPMENT OF VEGETATION. 512 p., illus. Washington, D. C. (Carnegie Inst. Wash. Pub. 242).

(21) ———
1920. PLANT INDICATORS: THE RELATION OF PLANT COMMUNITIES TO PROCESS AND PRACTICE. 388 p., illus. Washington, D. C. (Carnegie Inst. Wash. Pub. 290)

(22) Coville, F. V.
1920. THE INFLUENCE OF COLD IN STIMULATING THE GROWTH OF PLANTS. Jour. Agr. Research 20: 151–160, illus.

(23) Dixon, H. H.
1909. NOTE ON THE TENSILE STRENGTH OF WATER. Sci. Proc. Roy. Dublin Soc. (n.s.) 12: 60–65.

(24) ———
1909. VITALITY AND THE TRANSMISSION OF WATER THROUGH THE STEMS OF PLANTS. Sci. Proc. Roy. Dublin Soc. (n. s.) 12: 21–34, illus.

(25) ——— and Atkins, W. R. G.
1910. ON OSMOTIC PRESSURE IN PLANTS; AND ON A THERMO-ELECTRIC METHOD OF DETERMINING FREEZING-POINTS. Sci. Proc. Roy. Dublin Soc. (n. s.) 12: 275–311.

(26) ——— ———
1912. CHANGES IN THE OSMOTIC PRESSURE OF THE SAP OF THE DEVELOPING LEAVES OF SYRINGA VULGARIS. Sci. Proc. Roy. Dublin Soc. (n. s.) 13: 219–222.

(27) ——— ———
1912. VARIATIONS IN THE OSMOTIC PRESSURE OF THE SAP OF ILEX AQUIFOLIUM. Sci. Proc. Roy. Dublin Soc. (n. s.) 13: 229–238.

(28) ——— ———
1912. VARIATIONS IN THE OSMOTIC PRESSURE OF THE SAP OF THE LEAVES OF HEDERA HELIX. Sci. Proc. Roy. Dublin Soc. (n. s.) 13: 239–246.

(29) Dixon, H. H., and Atkins, W. R. C.
1913. osmotic pressures in plants. I. methods of extracting sap from plant organs. Sci. Proc. Roy. Dublin Soc. (n. s.) 13: 422–433.

(30) ——— ———
1913. osmotic pressures in plants. II. cryoscopic and conductivity measurements on some vegetable saps. Sci. Proc. Roy. Dublin Soc. (n. s.) 13: 434–440.

(31) ——— ———
1913. osmotic pressures in plant-organs. III. the osmotic pressure and electrical conductivity of yeast, beer, and wort. Sci. Proc. Roy. Dublin Soc. (n. s.) 14: 9–12.

(32) ———
1914. on the tensile strength of sap. Sci. Proc. Roy Dublin Soc. (n. s.) 14: 229–234.

(33) ———
1914. transpiration and the ascent of sap in plants. 216 p., illus. London.

(34) ——— and Atkins, W. R. G.
1915. osmotic pressures in plants. IV. on the constituents and concentration of the sap in the conducting tracts, and on the circulation of carbohydrates in plants. Sci. Proc. Roy. Dublin Soc. (n. s.) 14: 374–392.

(35) ——— ———
1915. osmotic pressures in plants. V. seasonal variations in the concentration of the cell-sap of some deciduous and evergreen trees. Sci. Proc. Roy. Dublin Soc. (n. s.) 14: 445–461.

(36) ——— ———
1916. osmotic pressure in plants. VI. on the composition of the sap in the conducting tracts of trees at different levels and at different seasons of the year. Sci. Proc. Roy. Dublin Soc. (n. s.) 15: 51–62.

(37) Drabble, E., and Drabble, H.
1907. the relation between the osmotic strength of cell sap in plants and their physical environment. Biochem. Jour. 2: 117–132.

(38) Ewart, A. J.
1906. the ascent of water in trees. Phil. Trans. Roy. Soc. London (B) 198: 41–86.

(39) Fischer, A.
1891. beiträge zur physiologie der holzgewächse. Jahrb. Wiss. Bot. [Pringsheim] 22: 73–160.

(40) Fitting, H.
1911. die wasserversorgung und die osmotischen druckverhältnisse der wüstenpflanzen. Ztschr. Bot. 3: 209–275.

(41) Gortner, R. A., and Harris, J. A.
1914. notes on the technique of the determination of the depression of the freezing point of vegetable saps. Plant World 17: 49–53.

(42) ——— Lawrence, J. V., and Harris, J. A.
1916. the extraction of sap from plant tissues by pressure. Biochem. Bul. 5: 139–142, illus.

(43) HANN, J.
1903. HANDBOOK OF CLIMATOLOGY. Tr. by R. D. Ward. 437 p., illus. New York and London.

(44) HANNIG, E.
1912. UNTERSUCHUNGEN ÜBER DIE VERTEILUNG DES OSMOTISCHEN DRUCKS IN DER PFLANZE IN HINSICHT AUF DIE WASSERLEITUNG. Ber. Deut. Bot. Gesell. 30: 194–204.

(45) HANSON, H. C.
1917. LEAF-STRUCTURE AS RELATED TO ENVIRONMENT. Amer. Jour. Bot. 4: 533–560, illus.

(46) HARRIS, J. A., and GORTNER, R. A.
1914. NOTES ON THE CALCULATION OF THE OSMOTIC PRESSURE OF EXPRESSED VEGETABLE SAPS FROM THE DEPRESSION OF THE FREEZING POINT, WITH A TABLE FOR THE VALUES OF P FOR Δ=0.001° TO Δ=2.999°. Amer. Jour. Bot. 1: 75–78.

(47) ———
1915. AN EXTENSION TO 5.99° OF TABLES TO DETERMINE THE OSMOTIC PRESSURE OF EXPRESSED VEGETABLE SAPS FROM THE DEPRESSION OF THE FREEZING POINT. Amer. Jour. Bot. 2: 418–419.

(48) ——— LAWRENCE, J. V., and GORTNER, R. A.
1915. ON THE OSMOTIC PRESSURE OF THE JUICES OF DESERT PLANTS. Science 41: 656–658.

(49) ——— ———
1916. ON THE OSMOTIC PRESSURE OF THE TISSUE FLUIDS OF JAMAICAN LORANTHACEAE PARASITIC ON VARIOUS HOSTS. Amer. Jour. Bot. 3: 438–455, illus.

(50) ——— ——— and GORTNER, R. A.
1916. THE CRYOSCOPIC CONSTANTS OF EXPRESSED VEGETABLE SAPS, AS RELATED TO LOCAL ENVIRONMENTAL CONDITIONS IN THE ARIZONA DESERTS. Physiol. Researches 2: 1–49.

(51) ——— and POPENOE, W.
1916. FREEZING-POINT LOWERING OF THE LEAF SAP OF THE HORTICULTURAL TYPES OF PERSEA AMERICANA. Jour. Agr. Research 7: 261–268.

(52) ———
1917. PHYSICAL CHEMISTRY IN THE SERVICE OF PHYTOGEOGRAPHY. Science 46: 25–30.

(53) ——— GORTNER, R. A., and LAWRENCE, J. V.
1917. THE RELATIONSHIP BETWEEN THE OSMOTIC CONCENTRATION OF LEAF SAP AND HEIGHT OF LEAF INSERTION IN TREES. Bul. Torrey Bot. Club 44: 267–286.

(54) ——— and LAWRENCE, J. V.
1917. THE OSMOTIC CONCENTRATION OF THE TISSUE FLUIDS OF JAMAICAN MONTANE RAIN-FOREST VEGETATION. Amer. Jour. Bot. 4: 268–298.

(55) ——— ———
1917. THE OSMOTIC CONCENTRATION OF THE SAP OF THE LEAVES OF MANGROVE TREES. Biol. Bul. 32: 202–211.

(56) ——— ———
1917. CRYOSCOPIC DETERMINATIONS ON TISSUE FLUIDS OF PLANTS OF THE JAMAICAN COASTAL DESERTS. Bot. Gaz. 64: 285–305.

(57) ———
1918. ON THE OSMOTIC CONCENTRATION OF THE TISSUE FLUIDS OF PHANEROGAMIC EPIPHYTES. Amer. Jour. Bot. 5: 490–506.

(58) HARRIS, J. A.
1918. ON THE OSMOTIC CONCENTRATION OF THE TISSUE FLUIDS OF DESERT LORANTHACEAE. Mem. Torrey Bot. Club 17: 307–315.
(59) ——— GORTNER, R. A., and LAWRENCE, J. V.
1921. ON THE DIFFERENTIATION OF THE LEAF TISSUE FLUIDS OF LIGNEOUS AND HERBACEOUS PLANTS WITH RESPECT TO OSMOTIC CONCENTRATION AND ELECTRICAL CONDUCTIVITY. Jour. Gen. Physiol. 3: 343–345.
(60) ——— ——— ———
1921. THE OSMOTIC CONCENTRATION AND ELECTRICAL CONDUCTIVITY OF THE TISSUE FLUIDS OF LIGNEOUS AND HERBACEOUS PLANTS. Jour. Phys. Chem. 25: 122–146.
(61) ——— and OTHERS.
1921. MAXIMUM VALUES OF OSMOTIC CONCENTRATION IN PLANT TISSUE FLUIDS. Proc. Soc. Exp. Biol. and Med. 18: 106–109.
(62) HARVEY, R. B.
1918. HARDENING PROCESS IN PLANTS AND DEVELOPMENTS FROM FROST INJURY. Jour. Agr. Research 15: 83–112, illus.
(63) ———
1919. IMPORTANCE OF EPIDERMAL COVERINGS. Bot. Gaz. 67: 441–444.
(64) HAUCH, L. A., and RAVN, F. K.
1913. EGENS MELDUG. Forstl. Farsogsv. Danmark 4: 57–115, illus. French resumé, p. 109–115.
(65) HIBBARD, R. P., and HARRINGTON, O. E.
1916. DEPRESSION OF THE FREEZING-POINT IN TRITURATED PLANT TISSUES AND THE MAGNITUDE OF THIS DEPRESSION AS RELATED TO SOIL MOISTURE. Physiol. Researches 1: 441–454.
(66) HOAGLAND, D. R.
1919. RELATION OF THE CONCENTRATION AND REACTION OF THE NUTRIENT MEDIUM TO THE GROWTH AND ABSORPTION OF THE PLANT. Jour. Agr. Research 18: 73–117, illus.
(67) HOFF, J. H. van't.
1887. DIE ROLLE DES OSMOTISCHEN DRUCKES IN DER ANALOGIE ZWISCHEN LÖSUNGEN UND GASEN. Ztschr. Phys. Chem. 1: 481–508.
(68) ILJIN, V., NAZAROVA, P., and OSTROVSKAIA, M.
1916. OSMOTIC PRESSURE IN ROOTS AND IN LEAVES IN RELATION TO HABITAT MOISTURE. Jour. Ecology 4: 160–173.
(69) JOST, L.
1907. LECTURES ON PLANT PHYSIOLOGY. Tr. by R. J. H. Gibson. 564 p., illus. Oxford.
(70) KEEN, B. A.
1919. A QUANTITATIVE RELATION BETWEEN SOIL AND THE SOILS OLUTION BROUGHT OUT BY FREEZING-POINT DETERMINATIONS. Jour. Agr. Sci. 9: 400–415, illus.
(71) KNUDSON, L., and GINSBURG, S.
1921. SUGGESTIONS WITH RESPECT TO THE MEASUREMENT OF OSMOTIC PRESSURE. Amer. Jour. Bot. 8: 164–170, illus.
(72) KORSTIAN, C. F.
1917. THE INDICATOR SIGNIFICANCE OF NATIVE VEGETATION IN THE DETERMINATION OF FOREST SITES. Plant World 20: 267–287.
(73) ———
1919. NATIVE VEGETATION AS A CRITERION OF SITE. Plant World 22: 253–261.

(74) KORSTIAN, C. F.
1921. EFFECT OF A LATE SPRING FROST UPON FOREST VEGETATION IN THE WASATCH MOUNTAINS OF UTAH. Ecology 2: 47–52, illus.
(75) ———
1921. DIAMETER GROWTH IN BOX ELDER AND BLUE SPRUCE. Bot. Gaz. 71: 454–461, illus.
(76) ———
1921. EVAPORATION AND SOIL MOISTURE IN RELATION TO FOREST PLANTING. Trans. Utah Acad. Sci. 2: 116–117.
(77) ———
1921. RELATION OF PRECIPITATION TO HEIGHT GROWTH OF FOREST TREE SAPLINGS. Trans. Utah Acad. Sci. 2: 260–267, illus.
(78) LECLERC DU SABLON, M.
1904. RECHERCHES PHYSIOLOGIQUES SUR LES MATIÈRES DE RESERVES DES ARBRES. Rev. Gén. Bot. 16: 339–368, 386–401, illus.
(79) ———
1920. LE RÔLE DE L'OSMOSE EN BIOLOGIE. 190 p., illus. Paris.
(80) LEWIS, F. J., and TUTTLE, G. M.
1920. OSMOTIC PROPERTIES OF SOME PLANT CELLS AT LOW TEMPERATURES. Ann. Bot. 34: 405–416, illus.
(81) LIDFORSS, B.
1896. ZUR PHYSIOLOGIE UND BIOLOGIE DER WINTERGRÜNEN FLORA. Bot. Centbl. 68: 33–44.
(82) ———
1907. DIE WINTERGRÜNE FLORA; EINE BIOLOGISCHE UNTERSUCHUNG. Lunds. Univ. Årsskr. (n. f.) Bd. 2, Afd. 2, Nr. 13, 76 p., illus.
(83) LIVINGSTON, B. E.
1903. THE RÔLE OF DIFFUSION AND OSMOTIC PRESSURE IN PLANTS. 149 p. Chicago.
(84) ———
1906. THE RELATION OF DESERT PLANTS TO SOIL MOISTURE AND TO EVAPORATION. 78 p., illus. Washington, D. C. (Carnegie Inst. Wash. Pub. 50).
(85) ———
1909. RÔLES OF THE SOIL IN LIMITING PLANT ACTIVITIES. Plant World. 12: 49–53.
(86) ———
1911. THE RELATION OF THE OSMOTIC PRESSURE OF THE CELL SAP IN PLANTS TO ARID HABITATS. Plant World. 14: 153–164.
(87) ———
1913. OSMOTIC PRESSURE AND RELATED FORCES AS ENVIRONMENTAL FACTORS. Plant World 16: 165–176.
(88) ——— and HAWKINS, L. A.
1915. THE WATER-RELATION BETWEEN PLANT AND SOIL. 48 p., illus. Washington, D. C. (*In* Carnegie Inst. Wash. Publ. 204).
(89) ——— and KOKETSU, R.
1920. THE WATER-SUPPLYING POWER OF THE SOIL AS RELATED TO THE WILTING OF PLANTS. Soil Sci. 9: 469–485.
(90) MCCOOL, M. M., and MILLAR, C. E.
1917. THE WATER CONTENT OF THE SOIL AND THE COMPOSITION AND CONCENTRATION OF THE SOIL SOLUTION AS INDICATED BY THE FREEZING-POINT LOWERINGS OF THE ROOTS AND TOPS OF PLANTS. (Abstract) Soil Sci. 3: 113–138.

(91) McCool, M. M., and Millard, C. E.
1920. FURTHER STUDIES ON THE FREEZING-POINT LOWERING OF SOILS AND PLANTS. Soil Sci. 9: 217–228, illus.

(92) Mer, E.
1899. REPARTITION HIVERNALE DE L'AMIDON DANS LES PLANTES LIGNEUSES. Compt. Rend. Acad. Sci. [Paris] 112: 964–966.

(93) Merriam, C. H.
1898. LIFE ZONES AND CROP ZONES OF THE UNITED STATES. U. S. Dept. Agr., Bur. Biol. Sur. Bul. 10, 79 p., illus.

(94) Mitra, S. K.
1921. SEASONAL CHANGES AND TRANSLOCATION OF CARBOHYDRATE MATERIALS IN FRUIT SPURS AND TWO-YEAR-OLD SEEDLINGS OF APPLE. Ohio Jour. Sci. 21: 89–99.

(95) Miyake, K.
1902. ON THE STARCH OF EVERGREEN LEAVES AND ITS RELATION TO PHOTOSYNTHESIS DURING THE WINTER. Bot. Gaz. 33: 321–340.

(96) Niklewski, B.
1905. UNTERSUCHUNGEN ÜBER DIE UMWANDLUNG EINIGER STICKSTOFFREIER RESERVESTOFFE WÄHREND DER WINTERPERIODE DER BÄUME. Bot. Centbl., Beihefte 19: 68–117.

(97) Ohlweiler, W. W.
1912. THE RELATION BETWEEN THE DENSITY OF CELL SAPS AND THE FREEZING-POINTS OF LEAVES. Ann. Rpt. Mo. Bot. Gard. 23: 101–131, illus.

(98) Palladin, V. I.
[1918]. PLANT PHYSIOLOGY. Ed. by B. E. Livingston. 320 p., illus. Philadelphia.

(99) Pearson, G. A.
1920. FACTORS CONTROLLING THE DISTRIBUTION OF FOREST TYPES. Ecology 1: 139–159, 289–308, illus.

(100) Petersen, O. G.
1896. STIVELSEN HOS VORE LØVTRAEER UNDER VINTERHVILEN. Overs K. Danske Vidensk. Selsk. Fordhandl. 1896: 50–66.

(101) Pfeffer, W.
1877. OSMOTISCHE UNTERSUCHUNGEN. 236 p., illus. Leipzig.

(102) ———
1900. THE PHYSIOLOGY OF PLANTS; A TREATISE UPON THE METABOLISM AND SOURCES OF ENERGY IN PLANTS. Ed. 2, tr. by A. J. Ewart. v. 1. Oxford.

(103) Preston, J. F., and Phillips, F. J.
1911. SEASONAL VARIATION IN THE FOOD RESERVES OF TREES. Forest. Quart. 9: 232–243.

(104) Ramaley, F.
1907. PLANT ZONES IN THE ROCKY MOUNTAINS OF COLORADO. Science 26: 642–643.

(105) ———
1909. THE SILVA OF COLORADO. IV. FOREST FORMATIONS AND FOREST TREES. Univ. Colo. Studies 6: 249–281, illus.

(106) Reed, H. S.
1921. GROWTH AND SAP CONCENTRATION. Jour. Agr. Research 21: 81–98.

(107) Rigg, G. B.
1921. SOME FACTORS IN EVERGREENNESS IN THE PUGET SOUND REGION. Ecology 2: 37–46.

(108) Robbins, W. W.
1917. NATIVE VEGETATION AND CLIMATE OF COLORADO IN THEIR RELATION TO AGRICULTURE. Colo. Agr. Exp. Sta. Bul. 224, 56 p., illus.

(109) Rosa, J. T., Jr.
1921. INVESTIGATIONS ON THE HARDENING PROCESS IN VEGETABLE PLANTS. Mo. Agr. Exp. Sta. Research Bul. 48, 97 p.

(110) Rydberg, P. A.
1913–21. PHYTOGEOGRAPHICAL NOTES ON THE ROCKY MOUNTAIN REGION. Bul. Torrey Bot. Club 40: 677–686, 1913; 41: 89–103, 459–474, 1914; 42: 11–15, 629–642, 1915; 43: 343–364, 1916; 44: 431–454, 1917; 46: 295–327, 1919; 47: 441–454, 1920; 48: 315–326, 1921.

(111) Salmon, S. C., and Fleming, F. L.
1918. RELATION OF THE DENSITY OF CELL SAP TO WINTER HARDINESS IN SMALL GRAINS. Jour. Agr. Research 13: 497–506, illus.

(112) Sampson, A. W., and Allen, L. M.
1909. INFLUENCE OF PHYSICAL FACTORS ON TRANSPIRATION. Minn. Bot. Studies 4: 33–59.

(113) ———
1918. CLIMATE AND PLANT GROWTH IN CERTAIN VEGETATIVE ASSOCIATIONS. U. S. Dept. Agr. Bul. 700, 72 p., illus.

(114) ———
1919. PLANT SUCCESSION IN RELATION TO RANGE MANAGEMENT. U. S. Dept. Agr. Bul. 791, 76 p., illus.

(115) Shreve, F.
1915. THE VEGETATION OF A DESERT MOUNTAIN RANGE AS CONDITIONED BY CLIMATIC FACTORS. 112 p., illus. Washington, D. C. (Carnegie Inst. Wash. Pub. 217).

(116) Shull, C. A.
1916. MEASUREMENT OF THE SURFACE FORCES IN SOILS. Bot. Gaz. 62: 1–31, illus.

(117) Sinnott, E. W.
1918. FACTORS DETERMINING CHARACTER AND DISTRIBUTION OF FOOD RESERVE IN WOODY PLANTS. Bot. Gaz. 66: 162–175, illus.

(118) Tuttle, G. M.
1919. INDUCED CHANGES IN RESERVE MATERIALS IN EVERGREEN HERBACEOUS LEAVES. Ann. Bot. 33: 201–210, illus.

(119) ———
1921. RESERVE FOOD MATERIAL IN VEGETATIVE TISSUES. Bot. Gaz. 71: 146–151.

(120) Weaver, J. E., and Mogensen, A.
1919. RELATIVE TRANSPIRATION OF CONIFEROUS AND BROADLEAVED TREES IN AUTUMN AND WINTER. Bot. Gaz. 68: 393–424, illus.

(121) Weidman, R. H.
1921. FOREST SUCCESSION AS A BASIS OF THE SILVICULTURE OF WESTERN YELLOW PINE. Jour. Forest. 19: 877–885.

AN ASCIGEROUS STAGE AND SYNONOMY FOR FUSARIUM MONILIFORME [1]

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INTRODUCTION

Fusarium moniliforme was described by Sheldon (*23*)[3], working in Nebraska, in 1904. The fungus was of interest at that time because it was believed to be connected with an ergotism-like disease of domestic animals. State Pathologist Peters (*17*) and others investigating the disease found no ergot. They discredited other popular beliefs as to its cause. They found that the corn on farms where the disease existed was badly rotted with a pink fungus, while that on farms where the disease had not appeared was not so rotted. Feeding experiments were carried on, and from their results and because of the similar distribution of fungus and disease the conclusion was reached that a causal relationship existed.

Sheldon's contribution in this problem was a painstaking study and a careful description of the fungus itself. It was an unusual Fusarium in that it had microconidia in chains. His formal description follows:

> Sporodochium sub-effuse, salmon-pink; sporophores, simple or branched, usually opposite; microconidia continuous, oblong-ovoid, moniliform, 6-10μ long; macroconidia, falcate, acute, for the most part 3-septate, 25-40μ long.

Since 1904 *Fusarium moniliforme* has come up in the literature of this country again and again as a saprophyte or parasite on corn. Holbert and Hoffer (*12*) mention *Gibberella acervalis* (Moug.) Wr., as one of the factors in root, stalk, and ear rot diseases in Indiana. Norton and Chen (*15*) report *Oospora verticilloides* Sacc. as a corn seed parasite in Maryland, and associate it with barren distorted stalks and rootrot in the field. The relation of *G. acervalis* and *O. verticilloides* to *F. moniliforme* will be discussed.

Valleau (*27*, *28*) considers *F. moniliforme* an active parasite capable of causing root and stalkrots of corn under laboratory and field conditions, and states that ear and seed infection with the fungus probably is universal. Manns and Adams (*13*) report the occurrence of *F. moniliforme* as an internal infection of seed corn in seventeen of twenty-one States from which samples for examination had been received, the percentage ranging from 0.4 in North Dakota to 80 per cent in Louisiana. Sherbakoff (*25*) finds that in Tennessee, as well as in other States, the most common Fusarium of corn is *F. moniliforme*. A number of other investigators, as Burrill and Barrett (*1*), Garman (*7*, *8*), Hewitt (*11*), and Selby (*22*), mention a Fusarium of corn which may possibly be *F. moniliforme*.

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[2] The writer wishes to acknowledge the benefit of Miss Helen Johann's knowledge of Fusaria in general, and experience with *Fusarium moniliforme* in particular and to thank Dr. James G. Dickson for making the photomicrographs and Dr. A. G. Johnson for assistance in revising the manuscript.

[3] Reference is made by number (italic) to "Literature cited," pp. 921-922.

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STUDIES ON CONIDIA

In the present investigations *Fusarium moniliforme* has been found very commonly associated with corn. Extensive isolations have been made from various parts of plants taken from cooperative experimental plots of the United States Department of Agriculture at Bloomington, Ill., and Madison, Wis., at three different times since the fall of 1919, by Helen Johann and the writer. In all, about 350 plants have been studied, and *F. moniliforme* has appeared very frequently.

Some of the cultures of *Fusarium moniliforme* obtained in this way have been kept in the laboratory for observation. The total number isolated was so large as to make it impracticable to keep all of them. Cultures received from other States, namely, Indiana, Delaware, Maryland, North Carolina, California, Iowa, and Kentucky, have been added to the number. At present the stock includes about twenty-five strains.

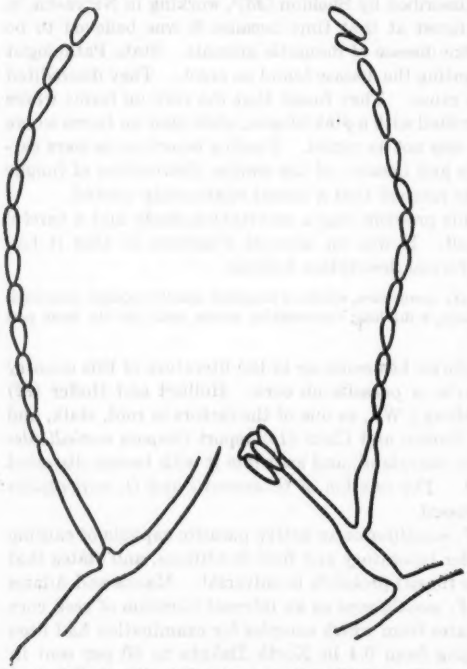


FIG. 1.—Microconidia of *Fusarium moniliforme* Sheldon. Typical of all strains observed. X 1733

It was noticed from time to time that these cultures differed from each other somewhat, and that some of them departed from Sheldon's description along certain lines. The production of sporodochia was one of the most noticeable of these points of difference. Some cultures developed them abundantly, in contrast with others where they were produced rarely or not at all, and in the true sporodochia a large number of 5-septate conidia was found with a corresponding maximum length greater than that given by Sheldon. All of them, however, had the catenulate microconidia of *Fusarium moniliforme* (fig. 1) and were confined to the same color range. They showed an early vacuolization and degeneration of macroconidia and mycelium, suggestive of the Section Roseum.

A detailed description of two of these cultures or strains, Y 15 and Y 29, will serve to illustrate some of the variations. Moreover, these two strains are of basic importance in the present discussion.

Descriptions are based on cultures grown at room temperature and on oat agar made according to the formula of Sherbakoff (*24, p. 105*) unless there is some statement to the contrary. Use of oat agar, potato-dextrose agar, potato-dextrose agar acidified, rye agar, bean agar, steamed rice, potato tuber plugs, Melilotus stems, sterilized wheat heads, sterilized corn stalks, and corn agar for these Fusaria has indicated that there is little to be gained from the variety, and that, in general, the oat agar is most satisfactory.

DESCRIPTION OF STRAIN Y 15

The macroconidia of strain Y 15 (fig. 2 and 3) are produced in pseudopionnotes or sub-effuse sporodochia rather than in well-rounded, distinct sporodochia as in Y 29. Ten representative macroconidia from the sources shown in Table I were measured and the averages of these measurements are given in Table I. It will be noted that 3-septate conidia predominate, but in the cases of certain sporodochia considerable percentages of 5-septate conidia were produced.

TABLE I.—*Average sizes of 3-, 4-, and 5-septate macroconidia, respectively, of strain Y 15 and percentages of each, from different sources*

Age of cultures	Source	Average sizes and percentages of each group in the total number—					
		3-septate		4-septate		5-septate	
Days		*Per cent*	*Microns*	*Per cent*	*Microns*	*Per cent*	*Microns*
60	Aerial mycelium	90	3.15 by 32.18	1	3.00 by 40.00	9	[a] 3.00 by 44.60
42	Sporodochium	54	3.32 by 30.18	0		46	3.00 by 45.27
42	Aerial mycelium	95	3.00 by 30.18	0		5	[a] 2.60 by 41.50
54		79	3.00 by 28.91	10	3.00 by 37.50	11	3.00 by 42.45
30	Pseudopionnotes	100	3.50 by 32.30	0		0	
41	Sporodochium	79	3.00 by 34.49	0		21	2.90 by 43.40
55	do	83	3.17 by 35.65	0		17	3.14 by 43.67
	Average		3.16 by 31.98				3.01 by 43.70

[a] Only one seen, not included in average.

Strain Y 15 produces blue-black globoid bodies resembling, macroscopically, the perithecia of *Gibberella saubinetii* (Mont.) Sacc., but smaller, being only 45 to 90μ in diameter. These are especially numerous in potato-dextrose agar, occurring as tightly packed groups or aggregates embedded in the medium. Microtome sections indicate that they are made up of what appears like outer walls of true perithecia, and have a small or no central empty space.

DESCRIPTION OF STRAIN Y 29

The macroconidia of Y 29 (fig. 4) are similar to those of Y 15 (fig. 2 and 3) except that 5-septate conidia are more common in the former strain. They predominate, in fact, and a number of 6-septate conidia also have been noted. As in the case of Y 15, 10 representative macroconidia from the sources noted in Table II were measured and the averages of these measurements are given in Table II. It will be noted that the length of the macroconidia averages somewhat greater in Y 29 even when equiseptate spores are compared.

TABLE II.—*Average sizes of 3-, 4-, 5-, and 6-septate macroconidia, respectively, of strain Y 29 and percentages of each, from different sources*

Age of cultures	Source	Average sizes and percentages of each group in the total number—							
		3-septate		4-septate		5-septate		6-septate	
Days		*Per cent*	*Microns*	*Per cent*	*Microns*	*Per cent*	*Microns*	*Per cent*	*Microns*
61	Sporodochium		[a] 3.50 by 36.60				3.44 by 53.98		
60	do		2.92 by 36.34		2.98 by 44.19		2.87 by 53.90		[b] 2.92 by 61.13
42		7	3.00 by 38.03			93	3.50 by 60.83		[c] 3.00 by 60.30
54		5	3.00 by 37.50	12	3.00 by 44.73	81	3.00 by 54.90	2	[d] 3.60 by 63.50
36	Sporodochium	5	3.00 by 37.80			95	3.00 by 58.20		
	Average		2.98 by 37.42		2.99 by 44.46		3.16 by 56.36		

[a] Only one seen, not included in average.
[b] Seven measured.
[c] Four measured.
[d] Two measured.

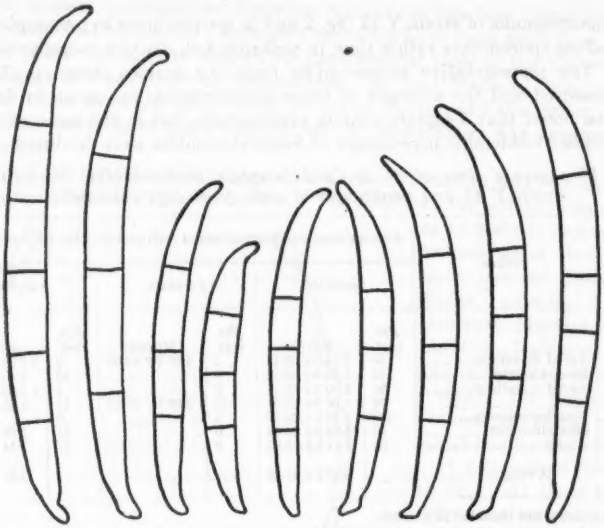


FIG. 2.—Macroconidia of strain Y 15 from pseudopionnotes of a culture 39 days old. X 1733

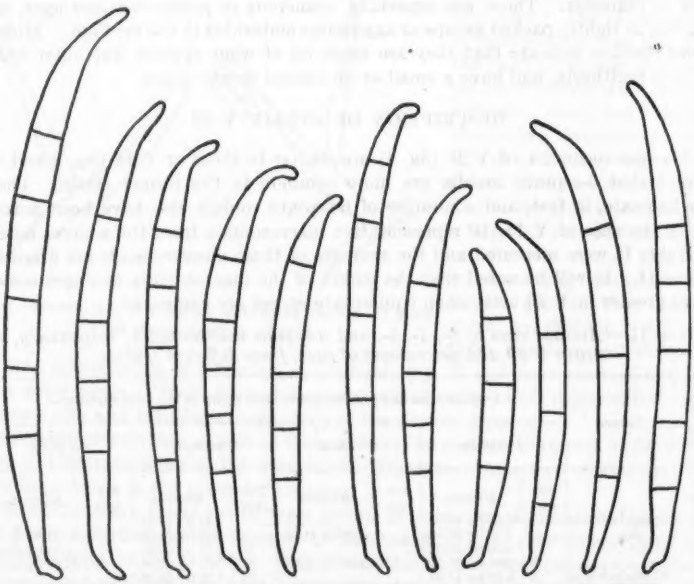


FIG. 3.—Macroconidia of strain Y 15 from sporodochium of a culture 34 days old. X 1733

In addition to these differences in morphology of macroconidia, strain Y 29 differs from Y 15 in that it shows a strong tendency to produce sporodochia of the usual *Fusarium moniliforme* vinaceous-cinnamon (*19*) and related shades, and also, sometimes produces blue-black plectenchymic sporodochia. Furthermore, strain Y 29 rarely produces the blue-black spherical bodies described for Y 15.

PRODUCTION OF AN ASCIGEROUS STAGE IN CULTURE

The blue-black globoid bodies described in Y 15, and found in a few of the total number of strains that have come into the laboratory, suggested the pos-

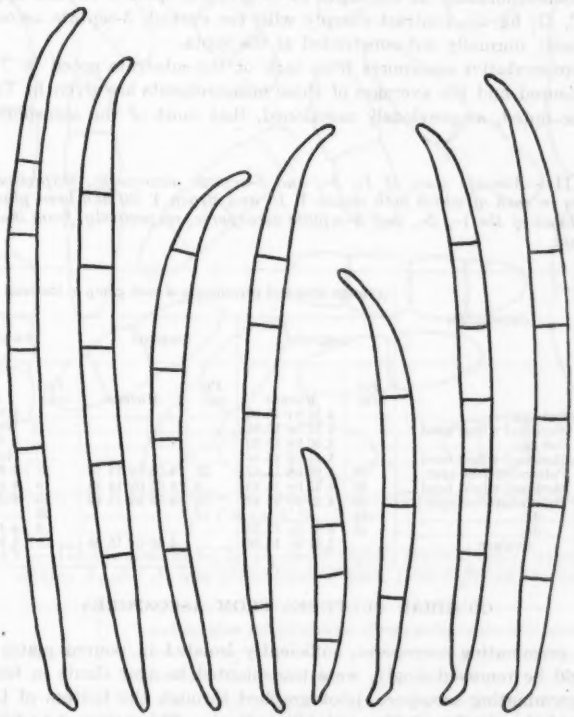


FIG. 4.—Macroconidia of strain Y 29 from sporodochium of a culture 66 days old. X 1733

sibility of a perfect stage. This led to constant examination of cultures for such a stage and to considerable experimentation in an effort to produce it. Various media, low and high temperatures, alternation of low and high temperatures, and other environmental variations were tried in culturing the fungus, but all failed to produce such a stage.

In September of 1922 perithecia appeared in a tube in which both Y 15 and Y 29 had been planted. The Y 15 had been placed at the top of the slant and the Y 29 at the bottom, and the perithecia developed along the line of contact of the two. The same thing occurred in the other of the two tubes similarly inoculated.

In an experiment started at that time a majority of 130 Petri dishes and tubes planted with both Y 15 and Y 29 produced perithecia (Pl. 1, A, B, C), while none of the 59 planted with Y 15 alone, and none of the 62 planted with Y 29 alone,

produced perithecia. In later experiments, perithecia have been found only in tubes or Petri dishes planted with Y 15 and Y 29 or with Y 15 and some other strain, but the yield has been smaller.

PERITHECIA

Macroscopically the perithecia are very similar to those of *Gibberella saubinetii*. Possibly this explains the fact that they have not been reported on corn. Microscopically there is not the least difficulty in distinguishing the ascospores of the two. The straight, usually 1-septate ascospores of the moniliform fungus, so constricted normally at the septa as to give the spore a swollen appearance (Pl. 2, C, D; fig. 5), contrast sharply with the curved, 3-septate ascospores of *G. saubinetii*, normally not constricted at the septa.

Ten representative ascospores from each of the substrata noted in Table III were measured and the averages of these measurements are given in Table III. It will be noted, as previously mentioned, that most of the ascospores are 1-septate.

TABLE III.—*Average sizes of 1-, 2-, and 3-septate ascospores, respectively, from cultures in each of which both strain Y 15 and strain Y 29 had been planted, and percentages of the 1-, 2-, and 3-septate ascospores, respectively, from the different substrata*

Age of culture	Substratum	Average sizes and percentages of each group in the total number—					
		1-septate		2-septate		3-septate	
Days		*Per cent*	*Microns*	*Per cent*	*Microns*	*Per cent*	*Microns*
61	Oat agar		4. 54 by 15. 00				4. 62 by 17. 32
55	Sterilized wheat head		4. 82 by 15. 83				None seen.
55	Oat agar		4. 40 by 15. 32				4. 43 by 16. 04
54	Sterilized wheat head		4. 51 by 15. 55				None seen.
55	Potato-dextrose agar	52	3. 95 by 14. 47	21	4. 08 by 14. 78	27	4. 31 by 15. 36
91	Sterilized wheat head	86	4. 35 by 15. 86	9	4. 01 by 14. 78	5	4. 13 by 16. 90
75	Potato-dextrose agar	69	4. 38 by 15. 47	15	4. 38 by 17. 40	16	4. 32 by 17. 40
74	do	61		17		22	
73	do	97	4. 31 by 17. 78			3	4. 42 by 18. 53
	Average		4. 41 by 15. 66		4. 16 by 15. 65		4. 37 by 16. 93

CONIDIAL CULTURES FROM ASCOSPORES

Single germinating ascospores, sufficiently isolated in poured plates so that they could be removed singly, were transplanted to agar slants in test tubes. Such a germinating ascospore, photographed through the bottom of the Petri dish before transferring, is shown in Plate 2, A. This colony transferred, became Fusarium strain A_1. A similar colony is shown in Plate 2, B. Still another similar colony from a 1-septate ascospore was isolated in a similar way and became Fusarium strain A_2.

While these Fusarium strains agreed in general with strains Y 15 and Y 29, including the production of microspores in moniliform chains, they have not shown the tendency of Y 29 to produce sporodochia. In form the macroconidia of strains A_1 and A_2 (fig. 6) are very similar to those of strains Y 15 and Y 29 (fig. 2 to 4). Ten representative macroconidia from strains A_1 and A_2 from each of the sources as noted in Table IV were measured and the averages are given. It will be noted that likewise in size the macroconidia of strains A_1 and A_2 are very similar to those of strains Y15 and Y 29 but that the former tend to average somewhat longer, except in the case of the 5-septate conidia of strain Y 29.

The blue-black globoid bodies described for strain Y 15 have been found occasionally in strain A_2. Perithecia have been produced in tubes in which strains A_1 and A_2 were planted together. They have not appeared in plantings of strain A_1 alone or of strain A_2 alone.

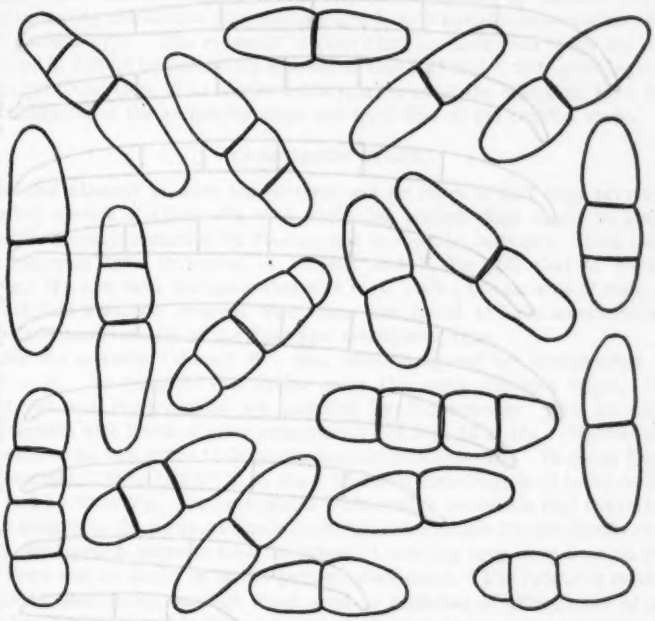


FIG. 5.—Ascospores from a potato-dextrose agar culture 67 days old, planted with both conidial strains Y 15 and Y 29. X 1733

TABLE IV.—*Average sizes of 3-, 4-, 5-, and 6-septate macroconidia, respectively, of strains A_1 and A_2 and percentages of each, from different sources*

Strain	Age of culture	Source	Average sizes and percentages of each group in the total number—							
			3-septate		4-septate		5-septate		6-septate	
	Days		*P. ct.*	*Microns*	*P. ct.*	*Microns*	*P. ct.*	*Microns*	*P. ct.*	*Microns*
A_1	32	Pseudopionnotes.	29	3.32 by 43.89	1	[a] 3.24 by 44.66	70	3.38 by 53.50	.....	0
A_1	41	.....	59	3.28 by 41.42	24	3.38 by 47.89	15	3.28 by 55.61	.....	0
A_1	42	Sporodochium.	26	3.00 by 41.50	.....	.....	74	3.00 by 52.12	.....	[b] 0
A_2	42	Pseudopionnotes.	70	3.30 by 31.70	5	[a] 3.30 by 42.49	25	3.23 by 48.30	.....	0
A_2	42	Sporodochium developed on wounded mycelium.	13	3.00 by 42.81	4	3.14 by 47.89	83	3.00 by 58.05	.....	[c] 3.00 by 72.35
A_2	54	Sporodochium.	32	3.23 by 38.83	.....	.....	68	3.29 by 51.86	.....	[d] 3.00 by 64.66
		Average	.....	3.19 by 40.02	.....	.....	.....	3.19 by 53.24	.....	.....

[a] Three measured. [b] Rare. [c] Two measured. [d] One measured.

There is as yet insufficient evidence to explain why perithecia have been obtained only where two strains have been planted together. Heterothallism is the first interpretation to present itself. Another possibility is that it is a case of chemical stimulation of one strain by the other. As bearing on the latter possi-

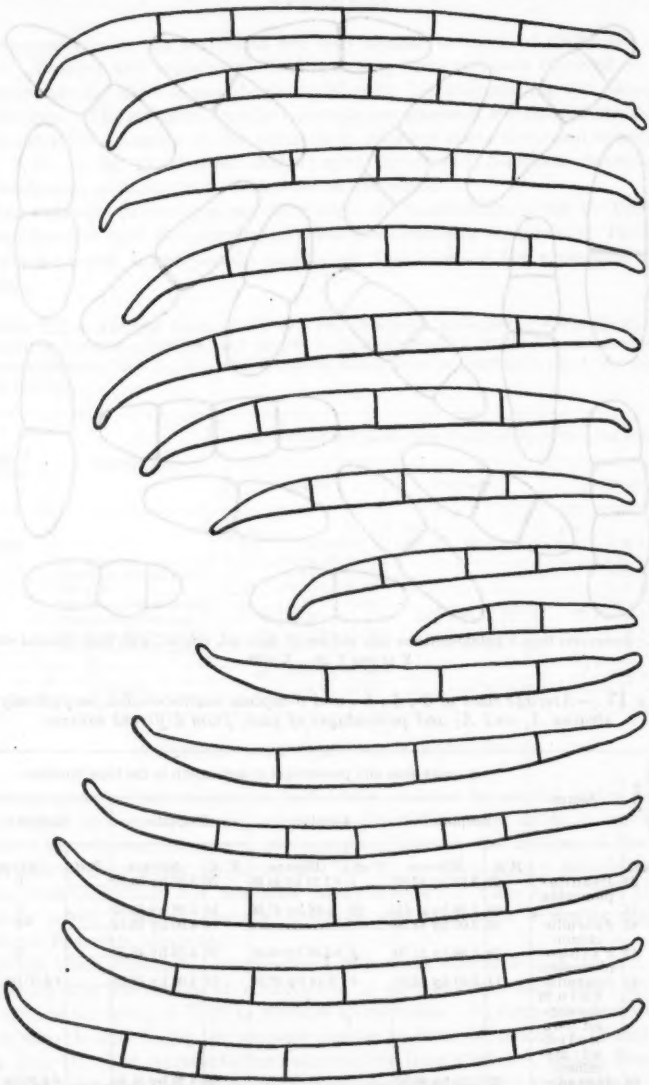


FIG. 6.—Macroconidia of strain A₃ from pseudoplasmotes of a culture, 42 days old, derived from an ascospore. X 1733

bility, Heald and Pool (*10*) report that *Fusarium moniliforme* produces metabolic products which have such a stimulating effect on an entirely different fungus. They grew it with *Melanospora pampeana* Speg. with the result that the latter fungus was stimulated to produce perithecia. It is hoped that investigations in progress may yield contributions along these lines.

NOMENCLATURE AND SYNOMOMY

From the evidence previously presented it seems reasonable to consider the variations in conidial cultures of strains Y 15, Y 29, A_1 and A_2 within the range of variations in a species of this group. While each of these conidial strains differs slightly from *Fusarium moniliforme* as originally described by Sheldon (*23*), all agree in having moniliform microconidia and 3- to 5-septate macroconidia of the same general type. The evidence is clear that an ascigerous stage has been produced in culture by permitting conidial strains Y 15 and Y 29 to grow together.

The problem, then, is to choose a binomial to meet the situation, both from the standpoint of the ascigerous stage and from that of the conidial stage.

ASCIGEROUS STAGE

The first attempt to solve the problem was an effort to find some previously described species of Gibberella with which the perfect stage might be placed. *Gibberella acervalis* seemed to be the only one to consider seriously. This species was suggested by a statement of Holbert and Hoffer (*12*) that *G. acervalis* (Moug.) Wr. non Sacc. was associated with root-, stalk-, and ear-rots of corn, and the fact that a culture received from them was found to have microconidia in chains and macroconidia of the *Fusarium moniliforme* type.

Gibberella acervalis (Moug.) Wr. non Sacc. is figured by Wollenweber (*29, Pl. 2 to 4*). No complete description under this name has been found. Only ascospores and macroconidia are included by Wollenweber. The ascospores are 1-septate with limits of measurements 4.5 to 5.5 by 12 to 17μ. Macroconidia are pictured on two of the three plates devoted to *G. acervalis*. Those on Plate 2 are 3-septate, 2.75 to 3.25 by 25 to 38μ. Those on Plate 3 are 3- (3 to 5-) septate, 2.25 to 3 by 30 to 50μ. On both plates Wollenweber comments that the relation of the conidia to the perfect stage is doubtful, but on Plate 2 a peculiarity in the Latin construction suggests that the intended meaning may have been to state that there was no doubt as to the genetic relationship. The fungus is reported as having been found only on wood, such as branches of alder, roots of oak, branches of willow, and juniper.

The size and form of the ascospores and macroconidia described by Wollenweber correspond rather closely with those of the fungus under consideration in this paper. However, no 3-septate ascospores are mentioned, and no microconidia, to say nothing of microconidia in chains, and the substrata for the two are widely different.

Gibberella acervalis (Moug.) Sacc. (*21 p. 318*) seems no more likely to be the perfect stage of the corn fungus than *G. acervalis* (Moug.) Wr. It is described as having only 3-septate ascospores, 6 by 8μ, and includes a spermogonial stage with spermogonia about a third as large as the perithecia, and spermatia very small, cylindrical, and oscillatory. It also is reported as having been found on wood.

It would seem, therefore, that neither *Gibberella acervalis* (Moug.) Wr. nor *G. acervalis* (Moug.) Sacc. covers the present case.

CONIDIAL STAGE

Norton and Chen (*15*) call attention to the fact that the fungus *Oospora verticilloides* Sacc. is very similar to or identical with Sheldon's (*23*) *Fusarium moniliforme*. They use the name *O. verticilloides* for the fungus from sweetcorn seed with which they were working, and add that if it should produce Fusarium macroconidia it would be identical with *F. moniliforme* Sheldon, but that the logical name for the fungus would be *Fusarium verticilloides*. Cultures kindly supplied by Norton and Chen produced Fusarium macroconidia when grown on oat agar in the present investigations.

96039—24†——6

Likewise, Manns and Adams (*14*) state that—

> The fungus *Oospora verticilloides* described by Saccardo on corn is no doubt identical with *Fusarium moniliforme*.

Oospora verticilloides Sacc. (*20, v. 2, p. 546*) has been discussed by European writers chiefly in its supposed etiological relation to pellagra. There is nothing about the original description or the illustration which disagrees with the microconidia of *Fusarium moniliforme*, but the description is somewhat lacking in detail. A translation of the description is as follows: Colonies white, conidiophores simple, branched or subverticillate, conidia in short chains, and oblong-fusoid or sub-obclavate, 2.5 to 3 by 8 to 10μ, hyaline, found on broken corn kernels.

Cuboni (*2*), working on pellagra in Italy, in 1882, reported a fungus almost universally present in corn of both good and poor quality in the pellagra districts, which he referred provisionally to Saccardo's *Oospora verticilloides*. He based the identification on Saccardo's illustrations, as he did not have access to the description. Cuboni's description agrees with that of Saccardo, except that he does not mention the catenulate arrangement of conidia. His three figures, showing mycelium, microconidia, and germinating microconidia, add nothing to his description.

Deckenbach published articles on *Oospora verticilloides* in connection with pellagra in Bessarabia, in 1896 (*3*), 1899 (*4, 5*), and 1907 (*6*). The 1907 article is a summary and contains all his data on the fungus. He gives a more detailed account of it than Cuboni and reports it as a widespread parasite of corn everywhere in Bessarabia. It reaches the individual ovaries of the corn by following the silk before the milk stage. He speaks of the scattered infected kernels with their broken pericarps and crumbling white contents of starch grains and fungus spores standing out sharply against the amber-gold of the normal kernels. He mentions culturing it on agar, potatoes, beef-peptone-gelatin, sterilized corn, and sterilized corn meal. Growth on the first three media mentioned is light. The gelatin is liquefied by the fungus. The color on the corn and corn meal changes from white to pink in three or four weeks and finally intensifies to violet in six to eight weeks.

Tiraboschi (*26*), in 1905, also concerned with the cause of pellagra in Italy, gives a very careful and detailed description of *Oospora verticilloides*. The optimum temperature for the fungus he finds to be 25° to 30° C. He gives certain cultural characters on the following media: Potatoes moistened with Raulin's fluid, Raulin's fluid agar, broth, gelatin, corn decoction, and milk. He studied the formation of the chains of microconidia as it occurred around the margin of hanging-drop cultures.

Not all of the cultural methods of Tiraboschi have been duplicated by the writer with *Fusarium moniliforme*. There is nothing particularly distinctive about the cultural characters he mentions, and in general they are what one would expect of *F. moniliforme*. The morphological characters given for the fungus with which he worked are very detailed and agree perfectly with *F. moniliforme*. He even mentions the fact that the last formed conidium in the chain is shorter and more nearly round than those formed first, and that the proximal ends of the conidia are more acute than the distal ends. His drawings are careful and might well be those of *F. moniliforme*.

In addition to this, the specimens of corn kernels attacked by *Oospora verticilloides* Sacc. in D. Saccardo's Mycotheca italica as specimen No. 1372 collected at Udine, Italy, by Prof. Sbozzi in 1903, are very similar to the numerous specimens of attacked corn kernels examined in the present investigations. The lesions on the kernels of the Saccardo specimen, that is, the blisters and cracks, are identical with kernel lesions in which *Fusarium moniliforme* Sheldon is commonly found in this country. Microscopic examination of the Saccardo material showed

mycelium but no conidia. The mycelium is like that of *F. moniliforme* but might equally well be some other fungus.

Reviewing the data, it seems that only evidence of the presence of macroconidia in *Oospora verticilloides* is necessary to establish its identity with *Fusarium moniliforme*.

Cuboni (*2*) states that occasionally he found a spore with two or three divisions, but there is nothing in his drawings to indicate macroconidia. No other reference to septate spores has been found.

To those who have worked with *Fusarium moniliforme*, this discrepancy will not appear impossible of explanation. The macroconidia found on corn are very few, so few ordinarily that they might not be found at all with examinations of abundant material, or probably would be regarded as spores of some other fungus. The variability of cultures in their tendencies to produce macroconidia is well known, and the media used by many of the investigators were not conducive to the production of macroconidia.

Since the evidence is so strongly in favor of *Oospora verticilloides* Sacc. and *Fusarium moniliforme* Sheldon being identical it seems unfortunate that the lack of description of macroconidia for the former species or an opportunity to compare authentic cultures of the two, makes it impossible to decide the case definitely.

Tiraboschi (*26*) considers the matter of synonomy and concludes that *Oospora verticilloides*, *O. hyalinula* Sacc., and *O. candidula* Sacc. are identical. He obtained specimens of *O. verticilloides* and *O. hyalinula* from Saccardo, and grew them and the fungus he, himself, had identified as *O. verticilloides* in parallel series on all the media he used. He states that he could not tell one from the other. He was not able to obtain a specimen of *O. candidula*, but notes that Saccardo pictures it with a branched chain of conidia, a condition never found in the fungus with which he was working. He includes it in synonomy, however, because Saccardo's description of it agrees more closely with his fungus than Saccardo's description of either *O. verticilloides* or *O. hyalinula* He also notes the fact that the name *O. hyalinula* antedates *O. verticilloides*, but chooses the latter name because it was established by the more complete description. *Oospora hyalinula* was originally described as *Torula hyalinula* Sacc. (*20, v. 1, p. 265*), the transfer to Oospora being made by Penzig (*16, p. 453*) for Saccardo. To these synonyms he adds the following list, doubtful not because their descriptions disagree with that of *O. verticilloides*, but because they are inadequate: *O. dubiosa* (Speg.) Sacc. and Vogl. ? *O. alba* (Preuss.) Sacc. and Vogl. ? *O. ovalispora* (Berk.) Sacc. and Vogl. ? *O. circinans* (Bon.) Sacc. and Vogl. ? *O. epilobii* (Cord.) Sacc. and Vogl. ? *O. hypoxylicola* (Preuss) Sacc. and Vogl. ? *O. nectricola* Rich. ?

Obviously the only way in which the relations of these various organisms can be satisfactorily determined is by comparing authentic cultures of them, a method not practicable for the present, at least. It does seem reasonable, however, to regard *O. hyalinula* as a synonym of *O. verticilloides* on the basis of the comparison of authentic cultures of them made by Tiraboschi.

Even the taxonomic meaning of Sheldon's *Fusarium moniliforme* is doubtful from the standpoint of the fusariologist. Sherbakoff (*25*) has stated that he believes there are several distinct species among those answering Sheldon's description of *F. moniliforme* and has established the new section, "Moniliform," for the group with the following characters:

> Macroconidia of intermediate Roseum-Elegans type, with very thin walls, mostly 3-septate; microconidia also in chains; no chlamydospores; color of substratum from none to violet.

Differences in the cultures studied in the present investigations might confirm this view. However, the following observations also have been made. Certain

strains that produced macroconidia in abundance at first lost this character after a time and afterwards produced nothing but mycelium and microconidia. Loss of color seemed to accompany this change in many cases. In a few instances cultures never produced pseudopionnotes or sporodochia, and showed very little color.

Loss of tendency to produce macroconidia in culture may be explained as due to growth under unfavorable conditions, or repeated transferring of mycelium or microconidia. Whether cultures that never produced sporodochia even from the time of isolation are to be interpreted as having been under unfavorable conditions in nature, or are to be considered species distinct from those that do produce sporodochia is not clear. On the whole it seems that insufficient evidence is at hand at present to justify the making of a number of new species. It seems preferable to retain the group under a single specific name with the understanding that a certain degree of variability is included.

Summarizing the situation, there can be no doubt as to the identity of *Fusarium moniliforme* Sheldon, when the name is used in the sense just defined and the conidial forms considered in this investigation. There is very little doubt as to the identity of *Oospora verticilloides* Sacc. with these forms, but the lack of a description or even definite mention of macroconidia in literature for *O. verticilloides*, and the lack of an opportunity to study an authentic culture of it, necessitate questioning the synonomy. *Oospora hyalinula* Sacc. is placed on an equal footing with *O. verticilloides* because of Tiraboschi's conclusion that they were identical after studying authentic cultures of them, as previously explained.

Thus only *Fusarium moniliforme* Sheldon remains to be considered if a conidial name is to be used for the new combination. This name seems particularly desirable in that it is the one best known to plant pathologists and will cause the least confusion in a new combination. The proposed new name and synonyms follow.

TECHNICAL DESCRIPTION

Gibberella moniliformis (Sheldon) n. comb.

? *Torula hyalinula* Sacc. 1878, Micothecae Venetae no. 1255; Michelia 1: 265; *Fungi italici delineati* no. 878.

? *Oospora hyalinula* Sacc. 1882, Penzig, Michelia 2: 453.

? *Oospora verticilloides* Sacc. 1882, Michelia 2: 546. *Fungi italici delineati* no. 879.

Fusarium moniliforme Sheldon, 1904, Nebr. Agr. Exp. Sta. Ann. Rpt. 17: 23–32, illus.

PERITHECIAL STAGE.—Perithecia scattered or gregarious, ovoid to sub-conical, free on the surface of the medium or embedded in mycelium, or in a tubercular plectenchymatic stroma, ostiolate, rarely 2-ostiolate, 225 to 300 by 300 to 375 μ; peridium of cells fairly uniform in size, and fairly smooth, blue-black when viewed macroscopically, dark blue by transmitted light; no paraphyses observed; ascospores 8, arranged irregularly in two rows, practically straight, fusiform to ellipsoid, rounded at the ends, often constricted at the septa, pale ochraceous salmon in masses, 1 to 3 septate, the 1-septate predominating, 3.9 to 4.8 by 15 to 19 μ.

CONIDIAL STAGE.—Microconidia produced basipetally on simple to verticillate conidiophores, adhering to form chains, or slipping aside to form balls or clusters at the ends of the conidiophores, obovoid to ellipsoid, 2 to 3.5 by 5 to 10 μ; macroconidia somewhat curved especially near the apex, gradually attenuate toward apex, pedicillate, borne on aerial mycelium, in pseudopionnotes or sporodochia, 3- to 5-septate; 3-septate conidia 2.9 to 3.2 by 32 to 40 μ; 5-septate conidia 3.0 to 3.2 by 44 to 56 μ; pseudopionnotes and sporodochia, pale ochraceous-salmon, vinaceous-cinnamon, or pale purplish vinaceous (*19*); mycelium dense, medium high, wooly, showing such colors as sea-shell pink, pale vinaceous fawn, pale purplish vinaceous, pale vinaceous-pink, purplish vinaceous, deep livid brown, pallid mouse gray, plumbago gray (*19*), substratum showing such colors as grayish olive, purplish gray, dark plumbago gray, vinaceous slate, dark vinaceous-drab, cinnamon drab and Indian purple (*19*).

HABITAT.—Perithecial stage known only in culture. Conidial stage very commonly associated with corn plants, as a saprophyte or parasite. Reported as a weak parasite in damping-off pine seedlings (*18*), as a cause of rootrot of older pines (*9*), and as having been isolated from rotted potato tubers (*19*). Probably a widespread saprophyte.

LITERATURE CITED

(1) BURRILL, T. J., and BARRETT, J. T.
1909. EAR ROTS OF CORN. Ill. Agr. Exp. Sta. Bul. 133: 64–109, illus.

(2) CUBONI, G.
1882. MICROMICETI DELLE CARIOSSIDI DI GRANO TURCO IN RAPPORTO COLLA PELLAGRA. Archiv. Psichiat., Sci. Penali ed Antropol. Criminale 3: 353–364, illus.

(3) DECKENBACH, C. v.
1896. ZUR BIOLOGIE DER OOSPORA VERTICILLOIDES SACC. Trav. Soc. Imp. Nat. St. Petersb. Compt. Rend. Séances 27: 130–131. [In Russian.]

(4) ———
1899–1900. DIE PILZE BESSARABIENS. Scripta Bot. Horti Univ. Imp. Petropolitanae 15: 57–108. [In Russian. German resumé, p. 101–108.]

(5) ———
1899–1900. DIE PILZKRANKHEITEN DER KULTURGEWÄCHSE DES BESSARABISCHEN GOUVERNEMENTS. Scripta Bot. Horti Univ. Imp. Petropolitanae 15: 127–152. [In Russian. German resumé, p. 151–152.]

(6) ———
1907. ZUR FRAGA ÜBER DIE AETIOLOGIE DER PELLAGRA. Centbl. Bakt. (I, Orig.) 45: 507–512.

(7) GARMAN, H.
1912. A PRELIMINARY STUDY OF KENTUCKY LOCALITIES IN WHICH PELLAGRA IS PREVALENT. Ky. Agr. Exp. Sta. Bul. 159: 1–79, illus.

(8) ———
1914. SOME KENTUCKY WEEDS AND POISONOUS PLANTS. Ky. Agr. Exp. Sta. Bul. 183: 253–339, illus.

(9) HARTLEY, C., MERRILL, T. C., and RHOADS, A. S.
1918. SEEDLING DISEASES OF CONIFERS. Jour. Agr. Research 15: 521–558, illus.

(10) HEALD, F. D., and POOL, V. W.
1909. THE INFLUENCE OF CHEMICAL STIMULATION UPON THE PRODUCTION OF PERITHECIA BY MELANOSPORA PAMPEANA SPEG. Nebr. Agr. Exp. Sta. Ann. Rpt. (1908) 22: 130–134, illus.

(11) H[EWITT], J. L.
1917. EAR MOLDS CAUSED BY FUSARIUM. U. S. Dept. Agr., Bur. Plant Indus., Plant Disease Bul. [1]: 52. [Mimeographed.]

(12) HOLBERT, J. R., and HOFFER, G. N.
1920. CONTROL OF THE ROOT, STALK, AND EAR ROT DISEASES OF CORN. U. S. Dept. Agr. Farmers' Bul. 1176, 24 p., illus.

(13) MANNS, T. F., and ADAMS, J. F.
1921. CORN ROOT ROT DISEASES. Del. Agr. Exp. Sta. Bul. 128, 24 p., illus.

(14) ——— ———
1923. PARASITIC FUNGI INTERNAL OF SEED CORN. Jour. Agr. Research 23: 495–524, illus.

(15) NORTON, J. B. S., and CHEN, C. C.
1920. ANOTHER CORN SEED PARASITE. Science 52: 250–251.

(16) PENZIG, O.
1882. FUNGHI AGRUMICOLI. Michelia 2: 385–508.

(17) PETERS, A. T.
1904. A FUNGUS DISEASE IN CORN. Nebr. Agr. Exp. Sta. Ann. Rpt. (1903) 17: 13–22, illus.

(18) RATHBUN, A. E.
1922. ROOT ROT OF PINE SEEDLINGS. Phytopathology 12: 213–220, illus.
(19) RIDGWAY, R.
1912. COLOR STANDARDS AND COLOR NOMENCLATURE. 43 p., illus. Washington, D. C.
(20) SACCARDO, P. A.
1877–82. FUNGI VENETI NOVI VEL CRITICI VEL MYCOLOGIAE VENETAE ADDENDI. Series VIII, XIII. Michelia 1: 239–275, 1877; 2: 528–563, 1882.
(21) ———
1878. ENUMERATIO PYRENOMYCETUM HYPOCREACEORUM HUCUSQUE COGNITORUM SYSTEMATE CARPOLOGICO DISPOSITORUM: Michelia 1: 277–325.
(22) SELBY, A. D.
1918. ROOT ROT OF CORN. Ohio Agr. Exp. Sta. Mo. Bul. 3: 313–314.
(23) SHELDON, J. L.
1904. A CORN MOLD. (FUSARIUM MONILIFORME N. SP.) Nebr. Agr. Exp. Sta. Ann. Rpt. (1903) 17: 23–32, illus.
(24) SHERBAKOFF, C. D.
1915. FUSARIA OF POTATOES. N. Y. Cornell Agr. Exp. Sta. Mem. 6: 87–270, illus.
(25) ———
1922. FUSARIA OF WHEAT AND CORN. (Abstract) Phytopathology 12: 45.
(26) TIRABOSCHI, C.
1905. SOPRA ALCUNI IFOMICETI DEL MAIS GUASTO DI REGIONI PELLAGROSE. Ann. di Bot. 2: 137–168, illus.
(27) VALLEAU, W. D.
1920. SEED CORN INFECTION WITH FUSARIUM MONILIFORME AND ITS RELATION TO THE ROOT AND STALK ROTS. Ky. Agr. Exp. Sta. Bul. 226: 25–51, illus.
(28) ———
1921. RESISTANCE AS A BASIS OF CONTROL OF CORN ROOT ROT. (Abstract) Phytopathology 11: 34.
(29) WOLLENWEBER, H. W.
1917. FUSARIA AUTOGRAPHICE DELINEATA. Ann. Mycol. 15: 1–56. (509 plates issued separately in limited edition.)

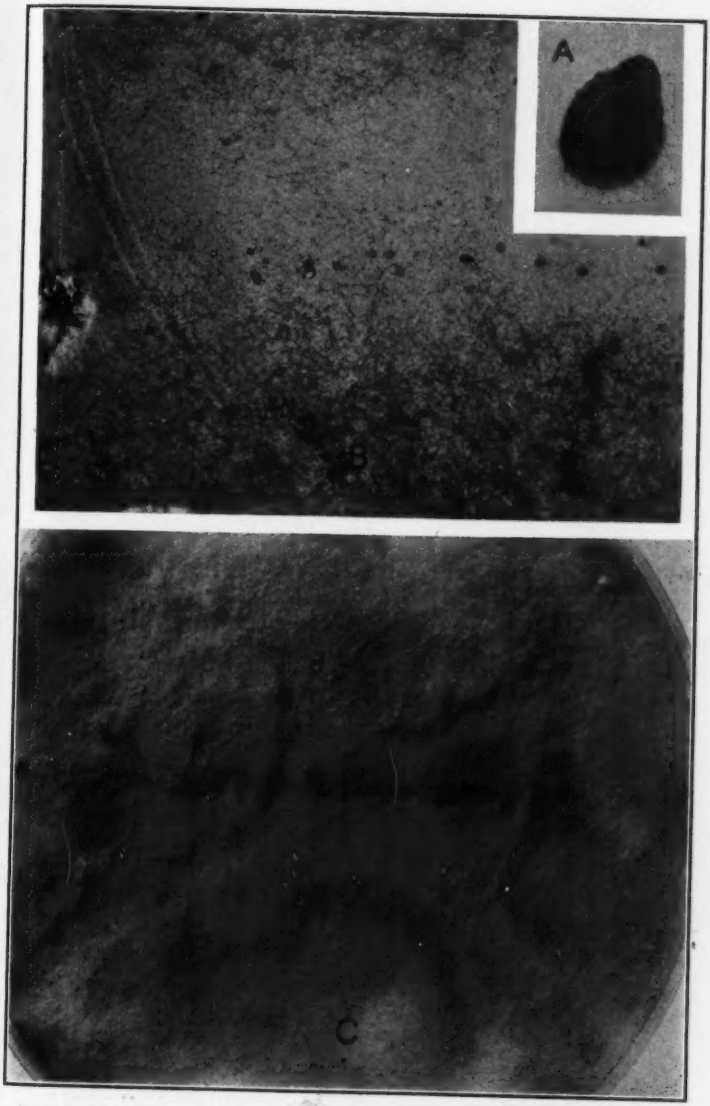
PLATE 1

Photomicrographs of *Gibberella moniliformis*

A.—Perithecium.

B.—Row of perithecia along the line of contact of Y 15 and Y 29 planted in a Petri dish on bean agar.

C.—Row of perithecia along the line of contact of Y 15 and Y 29 planted in a Petri dish on oat agar.


A
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C

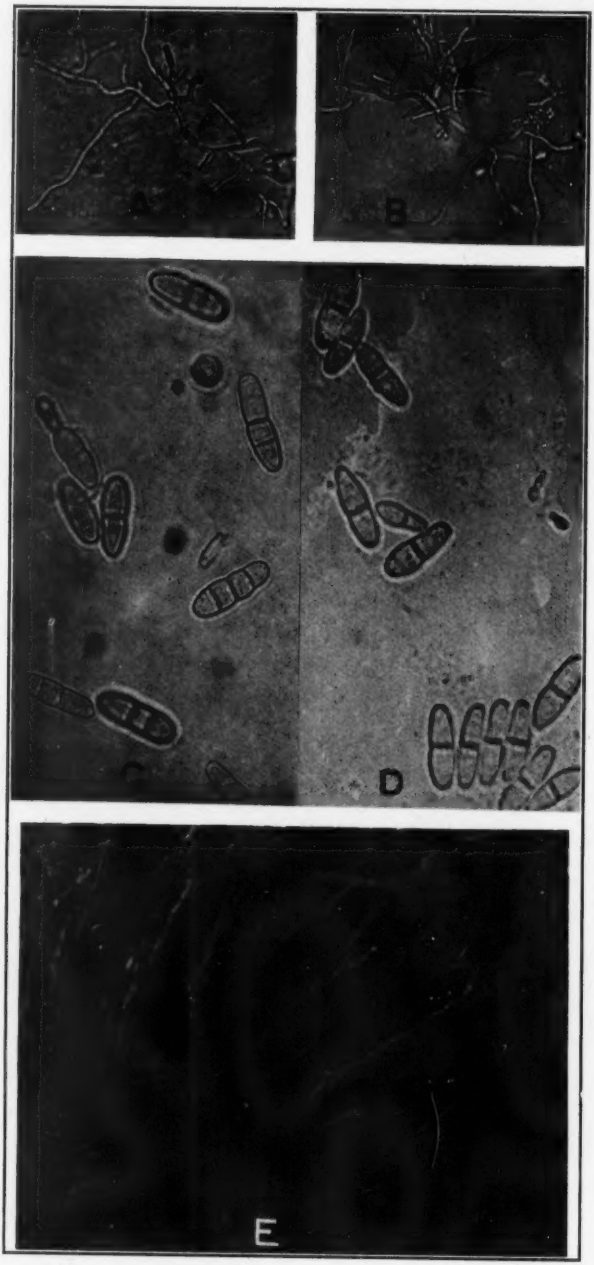
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PLATE 2

Photomicrographs of *Gibberella moniliformis*

A.—Colony developing from a 2-septate ascospore. X 190.
B.—Colony developing from a 1-septate ascospore. X 190.
C, D.—Ascospores. X 750.
E.—Ascospores in asci. X 750.

EXPULSION OF AECIDIOSPORES BY THE MAYAPPLE RUST, PUCCINIA PODOPHYLLI SCHW[1]

By B. O. DODGE

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The mechanics of spore discharge from an aecidium was recently discussed in a short account of the formation of germ pores of aecidiospores of *Gymnosporangium myricatum*.[2] The aecidiospore of the bayberry rust is provided with germ pores, six or seven in most cases. The writer found that, at the point where a germ pore is to be developed, there is a thickening of the spore wall over a small area in such a way that there is formed a little ball-like body, or "pore plug," which is separated from the rest of the spore wall. The germ pore becomes evident as soon as the plug is dislodged. By studying carefully stained sections of young aecidia it may be seen that the plug or pore formation begins with about the fourth spore in the chain and is completed when the spore reaches maturity. Seeing the spores densely packed in an aecidium, and with the spore walls deeply indented by the plugs, one readily understands how the plugs function in providing a more effective mechanism of spore discharge. Although the aecidiospore of the long-cycled orange-rust, Gymnoconia, on Rubus, does not form such pore plugs, still the spore is discharged with considerable force, proving that the plug, though serving a useful purpose in this connection, must act only in an accessory capacity in dislodging the spores in case of the bayberry rust. In view of the fact that such bodies have not been reported by those investigators who have studied the cytology of the rusts, it was thought likely that the persistence of that part of the spore wall as a little plug or ball filling or covering the germ pore was rather an unusual occurence. The writer has found a second species of rust where pore formation is accompanied by the development of similar bodies which persist as little plugs and no doubt take part in forcibly discharging the spores from the aecidium.

THE MAYAPPLE RUST, PUCCINIA PODOPHYLLI

The aecidia of *Puccinia podophylli* frequently cover large areas of the leaf so that the normal functioning of the lower epidermis must be seriously interfered with. The orange-rusts of Rubus are perennial. It was pointed out by the writer[3] that the presence of the gametophytic mycelium so stimulates the host that large numbers of stomata are formed on the upper side of the leaf where normally there are none. A similar study of Podophyllum leaves heavily infected with the mayapple rust sufficed to show that no such an effect follows the invasion of a leaf in this case. Stomata were rarely found on the upper side of the leaf, whether infected or not. Although the results of this study were disappointing, some further information was obtained relative to the discharge of the aecidiospores.

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[1] Received for publication July 23, 1924—issued Nov., 1924.

[2] DODGE, B. O. AECIDIOSPORE DISCHARGE AS RELATED TO THE CHARACTER OF THE SPORE WALL. Jour. Agr. Research 27: 749-765, illus. 1924.

[3] DODGE, B. O.—EFFECT OF THE ORANGE-RUSTS OF RUBUS ON THE DEVELOPMENT AND DISTRIBUTION OF STOMATA. Jour. Agr. Research 25: 495-500, illus. 1923.

It was noticed that where leaves were left in damp chambers overnight, aecidiospores would be found dusted over areas considerably beyond the margin bearing sori as though the spores had been discharged from the aecidia with some force. In order to prove whether this was a fact, the following simple method was employed. Petri dishes about 2 cm. in depth, containing a small amount of agar to maintain the desired humidity, were prepared. Small squares of the leaf bearing aecidia were set up against the side of the dish (fig. 1, F.) in such a way that should the spores be discharged violently, they would be shot out and come to rest on the agar. Within a few minutes after the apparatus was set up, it was found that a number of spores had already been discharged, some of them coming to rest fully a centimeter and a half from the point of discharge.

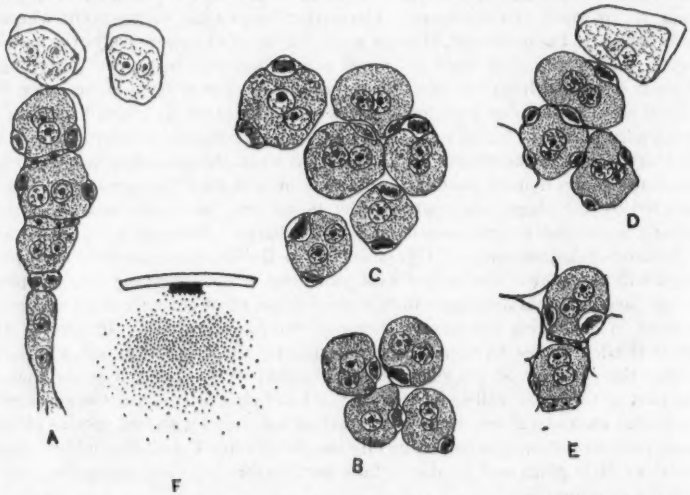


FIG. 1.—Aecidiospores of *Puccinia podophylli* Schw. (A), A chain of young spores showing the basal cell surmounted by three spores and a peridial cell. The first spore shows no local thickenings of the wall. The other two spores show two pore plugs. No plugs are developed in the walls of the peridial cells. (B) Four spores with one pore in each similarly located showing in this section. (C) Large spores with exceptionally large pore plugs. (D) Oblique section; four plugs in one spore. (E) Deep indentations in upper spore from pressure due to the development of the plugs and not to shrinkage in fixation. (F) Spore print of aecidiospores on agar. A small piece of leaf was fastened against the side of the Petri dish. As the spores were discharged they came to rest on the agar

After 18 hours, a definite spore print had been laid down. The largest number of spores had come to rest somewhat over one-half a centimeter away from the aecidia discharging them. During a number of trials, it was found that very few spores were shot beyond a distance of 1½ cm. In order to find out how high the spores could be shot vertically, pieces of the leaves bearing aecidia were laid on the agar in the bottom of the dish so that spores shot upward would strike the cover. To insure that the spores would stick to the cover, a thin layer of agar was spread over its surface. Very few spores were found on the cover when it was placed 1 cm. above the leaf.

Dr. A. H. R. Buller [4] has written the author that he believed a light object like an aecidiospore would be projected vertically just about as high as it would

[4] The reader will find an interesting account of experiments with the "toy balloon-gun" illustrating spore discharge in the following book: BULLER, A. H. R. RESEARCHES ON FUNGI. 2: 33-38. New York. etc. 1922.

be shot horizontally when projected from the aecidium. In other words, if the same force is applied to shoot a toy balloon upward vertically as is applied to throw it horizontally, the distance traversed by the balloon before it begins to fall in a straight line is about the same in both cases.

As only a few spores in each experiment were found at a distance of 1½ cm. from the aecidia, this may be assumed to be about the maximum horizontal distance that the spores could be thrown under these conditions. In the limited number of trials made to determine how high the spores could be shot the maximum distance seems to have been about 1 cm. No doubt if the experiments had been made with the rust on leaves attached to the plant the results would have been somewhat different.

SPORE DISCHARGE FROM AECIDIA OF GYMNOCONIA INTERSTITIALIS

Similar experiments were performed with orange-rust aecidia on leaves of Rubus. When small pieces of leaves bearing aecidia were employed the spores were shot vertically about 1 cm. but when entire leaves were used the vertical distance covered was somewhat greater, 1.3 cm. in some cases. Entire leaves were not used to determine the maximum horizontal distance. Using small squares of infected leaves, it was found that the maximum distance was about 1.1 cm. It makes a great deal of difference which orange-rust of Rubus is used in these experiments. The spores of the short-cycled form are rather waxy and tend to cling together so that they pile up in the sorus. Occasionally some of the spores are set free singly with a small amount of force so that they are found a few millimeters from their aecidia. On the other hand, when the long-cycled orange-rust is used a dusty spore print is laid down.

PORE FORMATION IN AECIDIOSPORES OF PUCCINIA PODOPHYLLI

The first thing that particularly attracts attention[5] in the examination of a spore print of the Podophyllum rust under the microscope is the large number of little bodies which lie around on the agar among the spores and attached to them. (Pl. 1.) These bodies resemble closely the "pore plugs" found attached to the spores of the bayberry rust previously mentioned. In order to prove whether or not they had the same origin, it was found necessary to study sections of young aecidia. Small pieces of leaf which showed the first signs of aecidial growth were fixed in Flemming's weaker fluid. Sections were stained with the triple stain. [5] In case of the Myrica rust the first indications of pore formation is seen in connection with the fourth or fifth spore in the chain. The process certainly begins earlier with the Podophyllum rust, for the second spore in the chain frequently shows one or two places where the wall is being disorganized around a thickened portion which takes the gentian violet stain. (Fig. 1, A.) The older the spore the larger the plugs become. If there are six or seven spores in the chain the plugs in the upper ones are so large as to indent deeply the walls of adjacent spores. In stained preparations the plug appears to lie in a cavity somewhat larger than the plug. There is no doubt that there is a certain amount of mucilaginous disorganization accompanying pore formation which also adds to the pressure, tending to spring back, or indent, the spore walls. The peridial cells at the upper end of a chain of spores never show germ pores or pore plugs. (Fig. 1, A.)

In favorably oriented sections three or four germ pores can be seen in one spore. (Fig. 1, D.) Exceptionally large pore plugs are shown in figure 1, C.

[5] Miss Ruth Colvin prepared the slides for this study and made the photographs which are reproduced in this paper.

As the spores mature and are discharged, the plugs appear to become rounded. (Pl. 1.) Some of them are dislodged during flight, others fall off as the spore comes to rest. One or two plugs may cling to the spore. Herbarium specimens of this rust show these bodies among the spores and they are undoubtedly always developed. Any object which could cause such indentations in elastic spore walls as are shown in figure 1, C, must certainly serve as a good fulcrum against which the spore wall can react as the spore breaks loose from its neighbors.

Dr. Buller has called the writer's attention, in an advance copy of a section which he has written for his new book on the fungi, to the work of Zalewski[6] on aecidiospore discharge. Zalewski found that in the case of four species of rusts the aecidiospores were discharged violently to a distance amounting in some instances to 1.5 to 2 cm. He also found that the spores were shot vertically to a height of 1.0 to 1.5 cm. This author gave no explanation of the phenomenon, and offered no suggestion as to the mechanics of the process.

SUMMARY

A study was made of the distribution of stomata on leaves of Podophyllum infected with the *Puccinia podophylli*. The host is not stimulated to develop additional stomata.

The germ pores of aecidiospores of this rust are developed as the result of localized thickenings of the wall in such a way that little plugs are formed and these become separated from the rest of the wall. The plugs, deeply indenting the elastic walls, serve as fulcrums against which the walls react as the spore is set free, so that it is discharged with considerable violence.

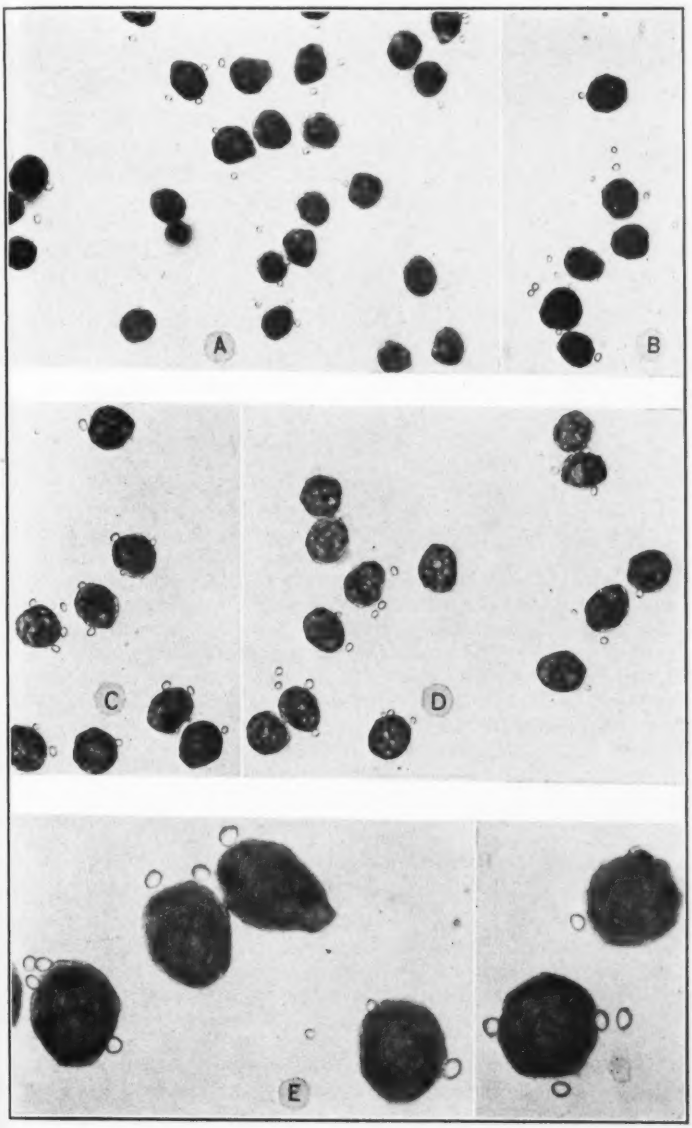
Persistent pore plugs are not developed by the aecidiospores of the orange rusts of Rubus. The spores of the long-cycled Gymnoconia are nevertheless discharged with some violence. Those of *Caeoma nitens*, being more waxy, tend to cling together and remain in the sorus, where they may germinate.

[6] ZALEWSKI, A.—Ueber sporenabschnurung und sporenabfallen bei pilzen. Flora 66: 228–234, 249–271. 1883.

PLATE 1

Puccinia podophylli Schw.

The aecidiospores were photographed as they had fallen on the agar after being shot horizontally about one centimeter. The pore plugs appear in the pictures as little circles, some of them still attached to the spores. A to D.—Photographed using an 8 mm. objective and × 10 Oc. E.—More highly magnified.


A
B
C
D
E

THE HEAT OF WETTING OF SOIL COLLOIDS[1]

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INTRODUCTION

The property of liberating heat on being wetted is well known to be characteristic of most colloidal substances and is generally thought to be essentially a function of surface. It was shown in a qualitative way over a century ago that certain powders liberate heat when wetted by liquids (*12*).[2] Soils and clays were included among the powders studied by some of the early investigators, who noted marked increases in temperature when the dry material was wetted by water and other liquids (*15*). Mitscherlich (*6*) was the first investigator to make a thorough study of the heat of wetting of soils. He used soils of different texture and varied the initial water content in a series of determinations. He was able to show a close relationship between heat of wetting and hygroscopicity, both of which he regarded as a measure of surface. He regarded the heat of wetting as a function of the colloidal material but considered the results as being of qualitative significance only, since the heat evolved probably depended upon the nature as well as upon the quantity of colloid present. Bouyoucos (*2*), however, has recently suggested that heats of wetting of soils should serve as a basis for the quantitative estimation of their colloid content. It is important in this connection to ascertain whether the colloidal material in different soils varies in heat of wetting.

Heat of wetting has been assumed by different investigators to be essentially a function of surface. The older concepts assumed that the effective surface could be determined microscopically (*9*). However, it is now recognized that this is impossible because of the submicroscopic size of many of the primary particles in substances having high heats of wetting. In the case of silica gel, Patrick and Grimm (*10*) have recently suggested that the surface influencing the heat of wetting is that of a water film surrounding silica nuclei which are approximately 5 $\mu\mu$ in diameter. The influence of surface of some kind upon colloidal properties is generally recognized. It is important, therefore, to know the heat of wetting of colloidal material from different soils, aside from any possibility that the determination could be used as a measure of the quantity of colloid in soils.

EXPERIMENTAL PROCEDURE

The method used for the determination of heat of wetting was very similar to that used by Patrick and Grimm (*10*) in their study of the heat of wetting of silica gel. The calorimeter consisted of a 150-cc. Dewar flask fitted with a fiber cap through which was inserted a small stirrer, a thermometer graduated to 0.025° C., and a short piece of No. 36 therlo wire, with copper leads, to serve as a heating coil. The whole apparatus was placed in a large air thermostat regulated to 25°.

The water equivalent of the calorimeter was determined by passing a measured electrical current through a heating coil of known resistance for 5 minutes and

[1] Received for publication July 2, 1924—issued Nov., 1924.

[2] Reference is made by number (italic) to "Literature cited," p. 935.

noting the rise in temperature. The water equivalent thus included the heating effect of the stirrer and loss due to radiation during the 5-minute period required for determinations. The water equivalent of the calorimeter was found to be 16.8 gm. of water. The specific heat of the soil or the colloid was taken as 0.2 in each case.[1]

A 5 to 15 gm. sample of soil or air-dried colloid was ground to pass a 50-mesh sieve, dried for 18 hours at 110° C., cooled, weighed, and placed in a desiccator in the thermostat, where it was brought to a temperature of 25°. Seventy-five grams of water were placed in the calorimeter and allowed to come to a temperature of 25° ±0.05°. When necessary a current was passed through the wire for a few seconds in order to reach more quickly the temperature desired. After reaching a temperature of 25°, the calorimeter was allowed to stand in the thermostat for at least 30 minutes before making a determination. It was found that under these conditions the temperature of the water would not vary more than 0.02° over a period of 5 minutes. Having thus reached constant temperature, the sample was added through a copper funnel inserted in a hole in the fiber cap. At the end of 5 minutes, the thermometer reading was taken. The temperature at the end of this time was usually at or near its highest point where it remained with slight recession for several minutes.

Duplicate determinations as a rule showed a maximum variation of about 0.5 calories per gram. This variation was just as great for materials of low heat of wetting as for those with high values. It is thus seen that for the average soil colloid the result is accurate within about 5 per cent; while for those of very low heat value the percentage may run considerably higher.

HEAT OF WETTING OF COLLOIDAL MATERIAL AND OF SOILS

The colloidal materials studied were prepared by the use of a supercentrifuge as described in a previous publication of this bureau (*4*). The particular samples used were selected from a list of some 50 which had previously been investigated for adsorptive capacities and chemical composition. They covered very nearly the variations in adsorptive capacity and chemical composition encountered in the 50 samples. It was therefore presumed that they would cover fairly well the range of heat of wetting values to be expected in the colloidal material from normal soils. The soils from which these colloids were extracted were some of the important soil types and differed widely in texture and other characteristics. The heats of wetting in water of the colloidal materials and corresponding soils are shown in Table I.

TABLE I.—*Heat of wetting of colloidal material and corresponding soil*

Type of soil or colloidal material	Heat liberated per gram of colloidal material	Heat liberated per gram of soil
	Calories	*Calories*
Cecil clay loam subsoil	4.5	1.6
Chester loam soil	7.2	1.1
Marshall loam soil	14.2	4.3
Miami silty clay loam subsoil	11.8	6.4
Norfolk fine sandy loam subsoil	6.0	1.5
Sassafras silt loam subsoil	9.8	2.2
Sharkey clay soil	16.3	9.6
Wabash silt loam soil	17.6	5.2

[1] Patten (*11*) found the specific heats of several soils, including sands, a muck and a clay, varied between 0.16 and 0.21. Mitscherlich (*7*) gives values for sands and clays ranging from 0.13 to 0.27. The heats of wetting of the samples tested would have been affected less than 1.6 per cent by a variation of 0.1 in the specific heat of the sample.

The heats of wetting of soil colloids are shown to be of an order comparable with those of organic and inorganic gels studied by various investigators. Rodewald (*14*) found 19.4 to 24 calories evolved per gram of starch. Bouyoucos[4] (*2*) found 9.6 calories per gram for "ferric hydroxide" and 21 calories for "aluminum hydroxide." Various investigators working with different preparations of silica gel have found from 6.9 to 24.2 calories per gram (*5*, *10*).

Table I shows that the heat liberated from the different soil colloids varies widely. For example, the Wabash colloid, which gives over 17 calories per gram, has nearly four times the heat value of the Cecil colloid with 4.5 calories. This difference is of about the same order as the difference in the extreme values for dye and ammonia adsorption.[5] The adsorption of water vapor, however, was much less variable.[6]

It is to be noted also in Table I that there is not much correspondence between the heat of wetting of the colloidal material and of the whole soil from which it was isolated. The heat liberated by the colloidal material was in some cases about twice that of the whole soil and in other cases more than six times the soil value. Certain of the soils gave higher heat values than the isolated colloids from other soils. The Miami, Sharkey, and Wabash soils, for instance, each gave a higher heat of wetting than the colloidal material from the Cecil. The heats of wetting of the different soils would not, therefore, be expected as a rule to show the relative quantities of colloidal material present. However, soils known to contain colloids of similar properties might be compared on the basis of heat of wetting of the whole soil and some idea of the relative colloid content be obtained.

HEAT OF WETTING OF NONCOLLOIDAL SOIL PARTICLES

It was shown in a former publication of this bureau (*1*) that the adsorptive capacity of the soil was associated almost entirely with the colloidal matter, and that the minerals making up the noncolloidal portion possessed but little adsorbing power. Of the common soil minerals, the micas were the only ones to show any significant adsorption. It was thought desirable to ascertain whether or not the heat of wetting of a soil was also practically all due to the colloidal material. The heat of wetting of mineral powders ground to a degree of fineness comparable with that of the minerals in the soil should show whether or not the noncolloidal part of the soil contributes appreciably to the heat of wetting of the whole soil.

For the study of mineral powders, commercial samples of quartz flour and orthoclase were used, all of which passed a 130-mesh sieve and contained much very fine material. Samples of hornblende and muscovite were prepared by grinding the minerals several days in a steel ball mill. These samples also passed a 130-mesh sieve and contained much that was very fine. The quartz, hornblende, and orthoclase each gave a temperature increase on wetting of less than 0.05° C., which was not greater than the probable error. Thus these common soil minerals above colloidal size would not contribute appreciably to the heat of wetting of a soil. Muscovite gave a heat of wetting of 1.3 calories per gram. This quantity is small, but it might constitute a significant part of the heat value of a soil containing a small quantity of colloid and a high percentage of mica. The

[4] These calculations are made on the basis of air dry weight.

[5] Additional data, as yet unpublished, indicate a close relationship between the heat of wetting power of a soil and its capacity to adsorb ammonia.

[6] It was indicated that the approximate constancy of the different colloids for water vapor adsorption probably applied only to an atmosphere whose humidity was similar to that produced by 3 per cent sulphuric acid (by weight). If stronger acid were used the results would be more variable (*4*, *p. 12*).

heat of wetting data closely parallel the results obtained in a more extensive study of soil minerals with respect to adsorption (*1*), indicating that the heat of wetting of a soil is almost entirely a function of the colloidal material.

HEAT OF WETTING AS A BASIS FOR ESTIMATING THE COLLOIDAL MATERIAL OF SOILS

While the heat of wetting of a soil is doubtless due almost entirely to the colloidal matter present, it is evident from the data given in Table I that the heats of wetting of different soils do not indicate the relative contents of colloidal material. This simple relationship does not obtain because of the wide variation in the heats shown by different colloids. It is possible, however, that the approximate colloidal content of a soil could be estimated from the heat of wetting of the soil if the heat of wetting of the particular kind of colloid present in the soil were known. If a sample of the colloidal material of a soil were extracted and the heat of wetting determined, then the formula

$$\frac{\text{heat of wetting per gram of soil}}{\text{heat of wetting per gram of colloid}} \times 100,$$

should indicate approximately the percentage of colloidal material in the soil. This general method of estimating the colloidal contents of soils from the standpoint of adsorptive capacities has been investigated in this bureau (*4*, *8*, *13*).

Table II shows the percentages of colloidal material present in eight soils, as indicated by the ratio of heat of wetting of soil to that of colloid. The data for this calculation are given in Table I. Table II also gives, for comparison, the percentages of colloid in the same soils indicated by adsorption ratios.

TABLE II.—*Percentages of colloidal material in soils calculated by heat of wetting ratio and by dye, water, and ammonia adsorption ratios*

	Colloidal material in soil indicated by heat of wetting ratio	Colloidal material in soil indicated by adsorption ratios		
		Dye	H_2O	NH_3
	Per cent	*Per cent*	*Per cent*	*Per cent*
Cecil clay loam subsoil	35.6	25.4	31.5	26.0
Chester loam soil	15.3	11.0	8.5	16.7
Marshall silt loam soil	30.3	26.3	27.3	33.6
Miami silty clay loam subsoil	54.2	54.8	50.1	54.2
Norfolk fine sandy loam subsoil	25.0	23.7	20.5	18.6
Sassafras silt loam subsoil	22.5	13.2	18.9	21.8
Sharkey clay soil	58.8	56.6	61.2	58.8
Wabash silt loam soil	29.5	29.4	29.8	34.5

The colloidal contents of the various soils indicated by the heat of wetting ratio agree well with the contents shown by one or more of the adsorption ratios. The heat of wetting ratio of soil and colloid obviously affords a more accurate estimation of the colloid content of a soil than the heat of wetting of the soil alone. It is probable, however, that even when heats of both soil and colloid are obtained the determination of the quantity of colloid in a soil is in most cases not strictly accurate, inasmuch as the heat of wetting ratios may be subject to the same inaccuracies as were found to affect adsorption ratios. A previous investigation (*4*) indicated that in estimating the colloidal content of a soil from the adsorption ratio of soil and colloid there might be two sources of inaccuracy, the possibility of the sample of colloid extracted not being representa-

tive in adsorptive capacity of all the colloidal material in the soil; and the possibility of the colloidal material having a different adsorptive capacity after isolation from what it had in the unextracted soil.

While it is a relatively simple process to isolate a small portion of the colloidal material from a soil, it is a long and tedious operation in most cases to extract as much as 50 per cent of the total colloid present. The data given in Tables I and II were obtained using samples which comprised not more than 5 per cent of the total colloidal material in the soil. Previous work indicated that such small samples differed by only about 10 per cent in adsorptive capacity from the bulk of the colloid that it was possible to extract. This small variation was shown by extracting successive portions of the colloidal material from several soils and testing the adsorptive capacities of the different fractions. A few of these samples which were not exhausted in the previous investigation were tested for heat of wetting. The results are shown in Table III, together with the adsorption data previously determined (*4, p. 18*).

TABLE III.—*Heats of wetting of colloid samples successively extracted from the same soil*

	Heat of wetting per gram of sample	Malachite green adsorbed per gram of sample	Water adsorbed per gram of sample	Ammonia adsorbed per gram of sample
Vega Baja clay loam soil:	*Calories*	*Gram*	*Gram*	*Gram*
First fraction of colloid	4.8	0.0584	0.3125	0.0206
Second fraction of colloid	4.4	.0463	.2749	.0165
Marshall silt loam soil:				
First fraction of colloid	12.2	.3159	.3090	.0611
Fourth fraction of colloid	9.8	.1916	.2328	.553

The variation in the heats of wetting of successively extracted portions of colloid was very similar to the variations in adsorptive capacities of the same samples. It is, therefore, to be assumed that the conclusion reached regarding adsorptive capacities on the basis of more extensive data applies in a general way to heat of wetting. That is to say, a small sample of colloid has, as a rule, only a slightly different heat of wetting from that of a sample which is a larger part of all the colloid.

Although the extractable part of the colloidal material of a soil may be fairly uniform in character, it does not follow that the part which is exceedingly difficult to isolate necessarily has the same properties. In determining the representativeness of a colloid sample with respect to heat of wetting it is important to consider also that portion which is not extractable by the ordinary means. In several instances separation of colloidal material has been made as completely as present methods will permit. By long and painstaking work of extraction 50 to 90 per cent of the total colloidal material present has been isolated from certain soils. The residues left after these extractions contained the so-called "unextractable" colloid. The heats of wetting of these residues were obtained; the percentages of colloid present were determined by W. H. Fry microscopically by a method previously described (*3*); and from these data the heats of wetting of the unextracted colloids were calculated.

Table IV gives a comparison of the heat of wetting of the extracted and of the unextracted colloidal material, together with data from which the heat of wetting of the unextracted colloid was calculated.

TABLE IV.—*Heats wetting of extracted and of unextracted colloidal material in soils*

Soil type	Determined heat of wetting per gram of colloid extracted from soil	Heat of wetting per gram of residue after extracting colloid	Colloid in residue by microscopical determination	Calculated heat of wetting per gram of colloid left in residue
	Calories	*Calories*	*Per cent*	*Calories*
Houston clay soil	11.6	2.1	40	5.2
Houston clay subsoil	10.5	1.2	32	3.8
Durham loam subsoil	5.3	[a] 1.9	11	17.3
Vega Baja clay soil	4.6	4.8	97	5.0

[a] This fine fraction contains considerable amounts of mica which may be responsible for a significant amount of this heat value.

The results given in Table IV indicate in three of the four cases studied a wide difference in the heat values of the extracted and unextracted colloids. These results are in accord with the data obtained in adsorption studies. It thus appears that in some soils, the part of the colloidal material which is difficult to isolate may have a very different heat of wetting from the part which is readily extracted. This fact tends to bring about more or less inaccuracy in estimating the colloidal content of a soil from the ratio of heats of wetting of soil and sample of colloid.

Evidence has been obtained that in the process of isolating and concentrating the colloidal material the adsorptive capacity of the colloid may be more or less altered. Apparently the heat of wetting property may also be subject to alteration.

Since practically all of the heat of wetting of a soil is due to the colloidal material, the ratio,

$$\frac{\text{Heat of wetting of soil}}{\text{Heat of wetting of colloid}},$$

should show the true quantity of colloid in the soil when the ratio is based on a fair sample of all the colloidal material present, unless the colloidal material after extraction has a different heat of wetting capacity from what it has in the untreated soil. By very thorough work, I. A. Denison, of this bureau, has isolated 76 to 88 per cent of the total colloidal material present in three soils. Owing to the completeness of the extraction, the colloidal material must be very nearly representative of all the colloid in the soils. Nevertheless, Table V shows that when heats of wetting of these samples are used in the ratio, quantities of colloidal material are indicated which are considerably in excess of true values. The true quantity of colloid in the soil is taken as the quantity actually isolated plus the quantity of unextracted colloid left in the residues estimated microscopically.

Table V gives the quantity of colloid in the soil indicated by the ratio and the heat of wetting values from which the ratio is calculated. The quantities of colloid extracted and true values for colloid content of the soil are also given in this Table.

The differences between the quantities of colloid indicated by heat of wetting ratios and by the combined extraction and microscopical determinations can not reasonably be attributed to failure to obtain a representative sample of the colloidal material for the heat of wetting ratios. Practically all the colloidal material was extracted for a sample. Moreover, it has already been shown that the so-called "unextractable" colloid usually has a lower heat of wetting capacity than the extracted material. Hence, if all the colloid had been extracted, to produce perfect samples, the heat of wetting ratios would presumably have been

slightly higher than the values obtained which were already too high. It would seem that the high values of the heat of wetting ratios are due to a reduction in the heat of wetting capacity of the colloid produced by extraction.

TABLE V.—*True colloid content of soil compared with content indicated by heat of wetting ratio when ratio is based on a large sample of colloid obtained by almost complete extraction of the soil*

Soil type	Heat evolved per gram of soil	Heat evolved per gram of colloid extracted	Colloid content as calculated by heat of wetting ratio	Colloid extracted as per cent of whole soil	Colloid left in residues as per cent of whole soil	True colloid content of soil
	Calories	*Calories*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Houston clay soil	9.5	11.6	89.1	53	17	70
Houston clay subsoil	10.8	10.5	102.9	66	10	76
Durham loam subsoil	2.2	5.3	41.5	16	2	18

More conclusive evidence that the process of extraction alters the heat of wetting of the colloid is obtainable from some of the data given in Tables IV and V. It can be shown that the sum of the heats of wetting of the extracted and unextracted colloids in the soil is in some cases appreciably less than the heat of wetting of the untreated soil. This would seem to show quite conclusively that in the cases studied the colloidal material as it exists in the untreated soil has a higher heat of wetting capacity than the colloid as it exists after isolation.

Table VI compares the heat of wetting of the untreated soil with the heats of wetting of the combined fractions into which the soil is separated by the process of extraction. The data for this comparison are given in Tables IV and V.[7]

TABLE VI.—*Influence of extraction upon the heat of wetting of soil colloids*

Soil type	Heat evolved by 1 gm. of untreated soil	Heat evolved by the extracted and unextracted colloid contained in 1 gm. of soil	Loss in heat of wetting per gram of soil due to process of extraction	Loss expressed as per cent of heat evolved by untreated soil
	Calories	*Calories*	*Calories*	*Per cent*
Houston clay loam soil	9.5	7.5	2.0	21
Houston clay loam subsoil	10.8	7.3	3.5	32
Durham loam subsoil	2.2	1.2	1.0	46
Vega Baja clay loam [a]	4.0	3.5	.5	13

[a] The colloid of the Vega Baja soil was not so completely extracted as in the case of the other three soils given in this Table. Details regarding the extraction of this sample are given in a previous publication of this bureau (4). The extracted colloid amounted to 29.3 per cent of the soil while the soil contained a total of 72.4 per cent of colloid.

The process of extraction in each case reduced the heat of wetting values of the soil material. In two cases the reduction in heat of wetting was of about the same order as the probable error. In the other two cases, however, the differences were sufficiently great to be of undoubted significance. These results are

[7] For example, the heat of wetting of the Houston soil is 9.5 calories per gram and the colloid extracted from it 11.6 calories per gram (Table V). This soil contains 53 per cent extractable colloid (Table V). The colloid extracted from 1 gm. of soil would, therefore, give 6.6 calories. This soil also contains 17 per cent of unextracted colloid (Table V) which gives a heat value of 5.3 calories per gram (Table IV). The unextracted colloid in 1 gm. of soil, therefore, amounts to 0.9 calories, making a total of 7.5 calories for the fractions from 1 gm. of soil after extraction, as compared with 9.5 calories for the untreated soil.

in accord with evidence of alteration which was obtained in the case of adsorption studies where water vapor and ammonia were the substances adsorbed (4).

It is not clear just how the process of extraction influences the heat of wetting of the colloid. It may be influenced to some extent at least by the structure of the aggregates of the colloidal material. The state of aggregation or structure of the particles in the colloidal material probably has considerable effect upon its heat of wetting and other physical properties. The same colloidal material will doubtless vary in its active surface according to whether the primary particles are present in loose or in compact aggregations. The arrangement of the colloidal particles is no doubt changed through the process of dispersion, subsequent concentration and drying. It is reasonable to assume that such changes as these are largely responsible for the alteration in heat of wetting values and may be responsible for the alteration in adsorptive capacity for ammonia or water.

In estimating the colloid content of a soil from the ratio,

$$\frac{\text{heat of wetting of soil}}{\text{heat of wetting of colloid}},$$

the value should be too high, provided alteration were the only source of inaccuracy. It has been shown, however, that the extracted colloids usually give higher heat of wetting values than the so-called "unextractable" portions. Furthermore, a small portion of the colloid extracted from a soil tends to give a higher heat of wetting than a larger sample (Table III). The error due to the quantity of colloid sample extracted and the error due to alteration, are, therefore, in opposite directions. If both errors were of the same magnitude the heat of wetting ratio should give a true expression of the quantity of colloid in a soil. Inasmuch as the sampling error tends to be less the larger the sample and the alteration error is probably greater the larger the sample, it is presumable that some size of sample from each particular soil would give a correct value for colloid content by the heat of wetting ratio. It is apparent that in case of very large samples (Table V) the alteration error was more than sufficient to balance the sampling error.

Ammonia adsorption studies indicate an alteration in adsorbing power due to extraction and also a sampling error similar to that found for heat of wetting (4). The colloid content of soils shown by heat of wetting ratios and by ammonia ratios (Table II) are as a rule in good agreement. Although complete confirmation is lacking, it seems probable that the small samples of colloid used in these ratios give errors so nearly compensating that the results usually approximate the true quantities of colloid present in the soils.

The heat of wetting method and the ammonia adsorption method for determining the colloidal content of soils appear to be of about the same value as regards practicability. Both require the extraction of a sample of the colloidal material, which involves considerable time as well as expense for apparatus. They do not appear to be as practicable as, and there is no evidence of their being more accurate than, the water adsorption method when the adsorption is conducted over 3 per cent sulphuric acid and a factor of 0.3 gm. of water per gram of colloid is taken as the constant value for soil colloids.

SUMMARY

The heats of wetting of soils and of colloidal material isolated from soils are given and the possibility of determining the colloidal content of soils from such data is discussed.

Heats of wetting of the colloidal materials from different soils vary widely. In some cases they are comparable with the heat values for starch and for synthetic inorganic gels.

Practically all of the heat of wetting of a soil appears to be due to colloidal material.

Although the colloid content of a soil can not be deduced from the heat of wetting of the soil alone, a fair approximation of colloid content may be indicated by the formula,

$$\frac{\text{heat of wetting of soil}}{\text{heat of wetting of colloid}} \times 100.$$

This method is subject to some inaccuracy, due to failure to isolate a sample representative of the whole of the colloid, and due to alteration of the colloid through the process of extraction. These errors, however, may be in opposite directions and in certain cases compensating. On the whole, the heats of wetting of soil and colloid probably indicate the colloid content of a soil about as accurately as adsorption determinations.

LITERATURE CITED

(1) ANDERSON, M. S., FRY, W. H., GILE, P. L., MIDDLETON, H. E., and ROBINSON, W. O.
1922. ABSORPTION BY COLLOIDAL AND NON-COLLOIDAL SOIL CONSTITUENTS. U. S. Dept. Agr. Bul. 1122, 20 p.

(2) BOUYOUCOS, G. J.
1924. EFFECT OF IGNITION AT VARIOUS TEMPERATURES UPON CERTAIN PHYSICAL PROPERTIES OF SOILS. Soil Sci. 17: 135–139.

(3) FRY, W. H.
1923. THE MICROSCOPIC ESTIMATION OF COLLOIDS IN SOIL SEPARATES. Jour. Agr. Research 24: 879–883.

(4) GILE, P. L., MIDDLETON, W. H., ROBINSON, W. O., FRY, W. H., and ANDERSON, M. S.
1924. ESTIMATION OF COLLOIDAL MATERIAL IN SOILS BY ADSORPTION. U. S. Dept. Agr. Bul. 1193, 42 p.

(5) LINEBARGER, C. E.
1901. ON THE HEAT EVOLVED WHEN LIQUIDS ARE BROUGHT IN CONTACT WITH POWDERS. Phys. Rev. 13: 48–54.

(6) MITSCHERLICH, E. A.
1905. BODENKUNDE FÜR LAND- UND FORSTWIRTE. 364 p., illus. Berlin.

(7) ———
1913. BODENKUNDE FÜR LAND- UND FORSTWIRTE. Ed. 2, 317 p., illus. Berlin.

(8) MOORE, C. J., FRY, W. H., and MIDDLETON, H. E.
1921. METHODS FOR DETERMINING THE AMOUNT OF COLLOIDAL MATERIAL IN SOILS. [PRELIMINARY PAPER.] Jour. Indus. and Engin. Chem. 13: 527–530, illus.

(9) PARKS, G. J.
1902. ON THE HEAT EVOLVED OR ABSORBED WHEN A LIQUID IS BROUGHT IN CONTACT WITH A FINELY DIVIDED SOLID. Phil. Mag. and Jour. Sci. (VI) 4: 240–253.

(10) PATRICK, W. A., and GRIMM, F. V.
1921. HEAT OF WETTING OF SILICA GEL. Jour. Amer. Chem. Soc. 43: 2144–2150, illus.

(11) PATTEN, H. E.
1909. HEAT TRANSFERENCE IN SOILS. U. S. Dept. Agr. Bur. Soils Bul. 59, 54 p., illus.

(12) POUILLET.
1822. MÉMOIRE SUR DE NOUVEAUX PHÉNOMÈNES DE PRODUCTION DE CHALEUR. Ann. Chem. et Phys. (II) 20: 141–162.

(13) ROBINSON, W. O.
1922. THE ABSORPTION OF WATER VAPOR BY SOIL COLLOIDS. Jour. Phys. Chem. 26: 647–653.

(14) RODEVALD, H.
1896. UNTERSUCHUNGEN ÜBER DIE QUELLUNG DER STÄRKE. 87 p., illus. Kiel and Leipzig.

(15) STELLWAAG, A.
1882. UNTERSUCHUNGEN ÜBER DIE TEMPERATURERHÖHUNG VERSCHEIDENER BODENCONSTITUENTEN UND BODENARTEN BEI CONDENSATION VON FLÜSSIGEM UND DAMPFFÖRMIGEM WASSER, SOWIE VON GASEN. Forsch. Geb. Agr. Phys. 5: 210–227.

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COMPARISON OF PIMA COTTON WITH UPLAND VARIETIES IN ARIZONA[1]

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INTRODUCTION

From the time the cotton industry in Arizona reached commercial importance, about 1915, until the season of 1922, the Salt River Valley of Arizona was maintained as a one-variety cotton community and received wide recognition as a source of production for American Egyptian cotton of high quality. Marketing conditions have not been favorable for Egyptian cotton since the war period, and each year larger quantities of Upland cotton have been grown. Only a few farmers planted Upland cotton in 1921, but in 1922 there were about 4,300 acres, and in 1923 about 58,000 acres. On the other hand, the planting of Pima cotton has been reduced from 73,000 acres in 1922 to about 40,000 acres in 1923. The future planting policy in the Salt River Valley is likely to be determined largely with reference to market conditions and prices.

Plantings have been made in each season since 1920 at the United States Field Station at Sacaton, Ariz., to compare the habits of growth and productiveness of the varieties considered best adapted for this region. The experiments consisted of quarter-acre blocks of seven rows of each variety, and the rows picked and recorded separately. The yield relations of the varieties differed with the seasons, but the plantings were not repeated in the way that is necessary to determine whether such differences are significant. Hence the results are not reported in an attempt to prove the superiority of any variety.

VARIETIES STUDIED AND METHODS EMPLOYED

In 1920 two Upland varieties, Lone Star and Durango, were compared with the Pima Egyptian variety. In 1921 the Acala variety was added to the series, and in 1923 the Hartsville and Mebane. The Acala is an Upland variety of Mexican origin which in recent years has been grown extensively in the San Joaquin and Coachella Valleys of California, in Oklahoma and northern Texas, and is rapidly increasing in popularity in Arizona and in the southwestern cotton growing States. The Hartsville is a long staple Upland variety from South Carolina originated by the United States Department of Agriculture and first distributed in 1907. The Mebane is a well known Texas big-boll variety with $1\frac{1}{16}$-inch staple. All of these varieties were planted to some extent in the Salt River Valley during 1922 and 1923, and are the only varieties that have received attention from the growers except a so-called "Delta" cotton which is indistinguishable from Hartsville.

The soil at Sacaton is an alluvial deposit of fine sand and silt, technically known as Pima sand, which has a high degree of fertility and a large water-holding capacity, making it very well adapted to cotton growing. The field used for the experiments is one of the most uniform on the station and offers special advantages for experimental studies of cotton.

[1] Received for publication Mar. 28, 1924—issued Nov., 1924.

The experiments were planted in adjacent blocks of seven rows of each variety, the same field being used each year, though the varieties were not kept in the same order. By referring to Table X the plats on which a particular variety was planted in each year can be ascertained.

The plantings were made as soon as danger of frost was past with a two-row planter adjusted for rows 44 inches apart. Seeding was at the rate of about 35 pounds of seed per acre. This is a somewhat higher rate than is generally used by commercial growers, but it has been found that this amount is required to insure a uniform stand which is necessary in experimental plantings. The date when the varieties were planted each year is given in Table I.

The height of the seedling plants when thinned varied somewhat in different years, but usually they averaged about 12 inches high, and were in no case allowed to grow over 15 inches in height before thinning. In all four years the plants were thinned as nearly as possible to one foot apart in the rows, which is the spacing most used by Pima cotton growers in Arizona. Thinning was never completed earlier than May 28 nor later than June 13.

TABLE I.—*Dates of planting variety tests at Sacaton, Ariz.*

Variety	1920	1921	1922	1923
Pima	Apr. 2	Apr. 9	Mar. 27	Apr. 18
Lone Star	do	do	[a]May 10	Do.
Durango	do	do	Mar. 27	Do.
Acala		do	Apr. 8	Do.
Mebane				Do.
Hartsville				Do.

[a] In 1922 Lone Star was first planted on Mar. 27 but poor germination and cold weather killed many of the young plants and further affected the stand, which necessitated the entire replanting of this plat on May 10.

Indications of water stress in Pima plants are easily recognized, and the irrigation problem is not very difficult after one becomes familiar with the characteristics of the plants. In the early stages of development, the irrigation water was applied at such intervals as was necessary to keep the plants from wilting, except during short periods in the middle of the day, and to prevent the upper fruiting branches from projecting above the terminal buds of the central stalk, which is an indication that growth is being checked. After flowering commenced the time of irrigation was governed largely by the position of the flowers. An effort was made to keep the flowers from appearing at the tops of the plants, except during the fall months when upward growth of the plants had practically ceased.

Plant behavior which indicates the proper time for irrigating the Upland varieties is much more difficult to recognize than with Pima. The flowers are hidden more by the leaves and do not appear at the tops of the plants until the cotton has been in distress for several days from lack of water. General wilting of Upland plants at any time of day during the summer months is usually an indication that water has been withheld too long.

The dates when water was applied to the different varieties in 1922 and 1923 are shown in Table II. Days on which more than 1 inch of rain fell are also included, as such rains were considered as the equivalent of an irrigation. These data are given for 1922 and 1923 only, as no detailed notes were taken in the previous years on flowering, shedding, and plant growth, in connection with which irrigation dates might be of interest.

TABLE II.—*Dates when variety plantings were irrigated and when over 1 inch of rainfall occurred at the United States Field Station, Sacaton, Ariz., in 1922 and 1923*[a]

1922

Month	Date of rain	Date of irrigation			
		Variety			
		Acala	Durango	Pima	Lone Star
April			28	28	
July		7	7	7	7
Do		25	25	25	
August					1
Do				8	8
Do	15	25			
Do					
September	31				
Do				15	
Do		19	19		

1923

Month	Date of rain	Date of irrigation					
		Variety					
		Hartsville	Durango	Pima	Acala	Mebane	Lone Star
May		29	29	29	29	29	29
June		29	29	29	29	29	29
July	13						
Do		24	24	24	24	24	24
August						6	6
Do		7	7	7	7		
Do		21	21	21	21	21	21
September		1	1	1	1	1	1
Do		11	11	11	11	11	11

[a] On Aug. 25, 1922, and on Oct. 2, 1923, the varieties were all watered to permit the proper maturing of the crop and had no effect on the shedding.

In 1922 and 1923 after the plants were thinned, and before any flowers had opened, a section consisting of 25 representative plants was selected in one of the interior rows of each variety. Detailed notes were taken daily on the behavior of these plants throughout the remainder of the season.

The height of the individual plants in each of the 25-plant sections was measured at weekly intervals through the season until growth had practically ceased. The number of flowers produced each day was recorded from the time of the appearance of the first flower until September 15. A small white tag bearing the date of flowering was fastened to the pedicel of each flower in such a manner that it remained attached to the young boll, even after shedding. Collections were made daily of the tags which had fallen with shed bolls, and the dates recorded. Thus a record of flowering and shedding was obtained for each day throughout the season. In 1923 the date of opening was recorded for each boll, which determined the period required for each boll to reach maturity.

VARIETAL DIFFERENCES IN PLANT GROWTH AND LENGTH OF ACTIVE GROWING PERIOD

In 1922 and 1923 measurements of height of the individual plants in the 25-plant sections of each variety were begun in the last week of June and continued for 12 weeks, or through the second week of September, covering the same period in which the flowering and shedding notes were taken. The average height of the plants of each variety at weekly intervals, and the increase in height over the previous week, are shown in Table III for 1922 and Table IV for 1923.

TABLE III.—*Average height in inches of 25 plants of each variety for each week, and the increase over the previous week, throughout the fruiting season of 1922*

Date	Acala		Durango		Pima		Lone Star	
	Average height	Average increase	Average height	Average increase	Average height	Average increase	Average height	Average increase
June 26	22.4		18.2					
July 3	27.1	4.7	23.1	4.9	24.8		19.9	
10	30.2	3.1	25.9	2.8	28.9	4.1	23.8	3.9
17	35.2	5.0	31.8	5.9	32.6	3.7	28.4	4.6
24	40.4	5.2	35.9	4.1	35.9	3.3	30.7	2.3
31	45.9	5.5	40.4	4.5	40.3	4.4	31.2	.5
Aug. 7	51.6	5.7	43.3	2.9	42.3	2.0	31.3	.1
14	54.2	2.6	43.8	.5	43.9	1.6	31.4	.1
21	55.2	1.0	44.3	.5	47.1	3.2	31.4	0
28	56.0	.8	44.6	.3	48.0	.9	31.4	0
Sept. 4	56.0	0	44.6	0	48.0	0	31.4	0
11	56.0	0	44.6	0	48.0	0	31.4	0

TABLE IV.—*Average height in inches of 25 plants of each variety for each week, and the increase over the previous week, throughout the fruiting season of 1923*

Date.	Hartsville		Durango		Pima		Acala		Mebane		Lone Star	
	Average height	Average increase	Average height	Average increase	Average height	Average increase	Average height	Average increase	Average height	Average increase	Average height	Average increase
June 25	17.7		20.0		19.3		19.2		18.5		15.8	
July 2	23.5	5.8	24.9	4.9	24.4	5.1	25.0	5.8	23.5	5.0	20.2	4.4
9	29.6	6.1	30.6	5.7	31.0	6.6	30.6	5.6	28.4	4.9	24.9	4.7
16	33.6	4.0	36.0	5.4	36.4	5.4	34.7	4.1	31.3	2.9	27.8	2.9
23	36.0	2.4	40.1	4.1	41.4	5.0	36.6	1.9	32.4	1.1	28.3	.5
30	37.0	1.0	42.1	2.0	46.4	5.0	37.8	1.2	33.2	.8	29.6	1.3
Aug. 6	37.3	.3	42.7	.6	50.4	4.0	38.3	.5	33.4	.2	29.8	.2
13	37.6	.6	42.9	.2	54.5	4.1	38.5	.2	33.4	0	29.8	0
20	37.8	.2	42.9	0	57.0	2.5	39.0	.5	33.4	0	29.8	0
27	38.0	.2	42.9	0	58.2	1.2	39.3	.3	33.4	0	29.8	0
Sept. 3	38.0	0	42.9	0	58.4	.2	39.4	.1	33.4	0	29.8	0
10	38.0	0	42.9	0	58.4	0	39.6	.2	33.4	0	29.8	0

It may be seen that in both these years the Durango, Acala, and Pima plants had a much longer period of active growth than Lone Star. The comparatively short growing period of Lone Star was also noticed in 1920 and 1921. The plant growth of Mebane in 1923 was much like Lone Star, although Mebane became slightly taller. These two varieties were the only ones which showed a decidedly shorter growth period than Pima, although the growing period of Durango, in both 1922 and 1923, was intermediate between these two varieties and Pima.

In 1923 the Pima plants continued in active growth for nearly a month after all the Upland varieties had practically ceased growing, but in 1922 the Acala was planted 12 days later than Pima and the plants continued to grow at nearly the same rate as Pima to the end of the season. Acala and Durango in 1923 ceased rapid growth much earlier than in the previous year, while the growth behavior of Pima and Lone Star in 1923 closely resembled their previous performance in 1922.

Figures 1 and 2 show in graphic form the growth rate data contained in Tables III and IV, which makes a direct comparison of the height and length of the growing period of the different varieties easier.

DIFFERENCES IN FLOWER PRODUCTION

The number of flowers produced each day in the 25-plant sections, the number of bolls that were shed, and the number of bolls that were retained and developed in the seasons of 1922 and 1923, are given in Tables V and VI. The Upland varieties began to flower about a week before Pima with the exception of the replanted Lone Star in 1922. Also the Upland varieties usually produce a larger number of flowers than does Pima, but this advantage is reduced by much greater shedding after flowering among the Upland varieties, so that

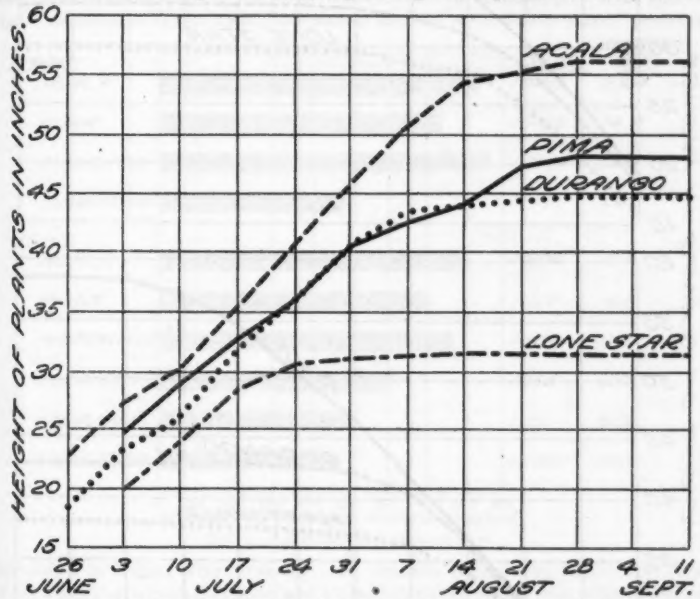


FIG. 1.—Average rate of growth for 25 plants in each variety from June 26 to September 11, 1922.

Pima matures more bolls than any of the Upland varieties. On the other hand, the greater number of Pima bolls is counterbalanced by the larger size of the Upland bolls.

It will be seen from figure 3 that the relations of the varieties in flower production were much the same in 1923 as in the previous year. The Acala variety produced on 25 plants a total of 1,948 flowers during the active flowering period of 1922, with a daily average of 23.4, while in 1923 only 1,290 flowers were produced, and the daily average was only 15.9. Such a difference may be attributed to soil variations which were not distinguishable when the 25 plants were selected for record purposes. In 1922 many of the late bolls on some of the varieties failed to reach maturity on account of an early frost, whereas in 1923 the season was longer, and practically all of the bolls matured and were picked. This accounts, in part, for the lack of a correlation between the flower production and yields in 1922 and 1923.

In 1922 the Durango plants continued flowering for 86 days, which was the longest period of active flowering recorded in either 1922 or 1923. In 1923, however, the active production of flowers by the Durango plants continued for

only 61 days, while Acala produced flowers for 81 days. The short flowering season of Lone Star in both years is noticeable in figure 3. Nevertheless, the total number of flowers and also the yield of this variety do not compare unfavorably with the varieties which continued to flower much longer. Mebane also had a very short flowering period in 1923 but was able to set a large number of bolls.

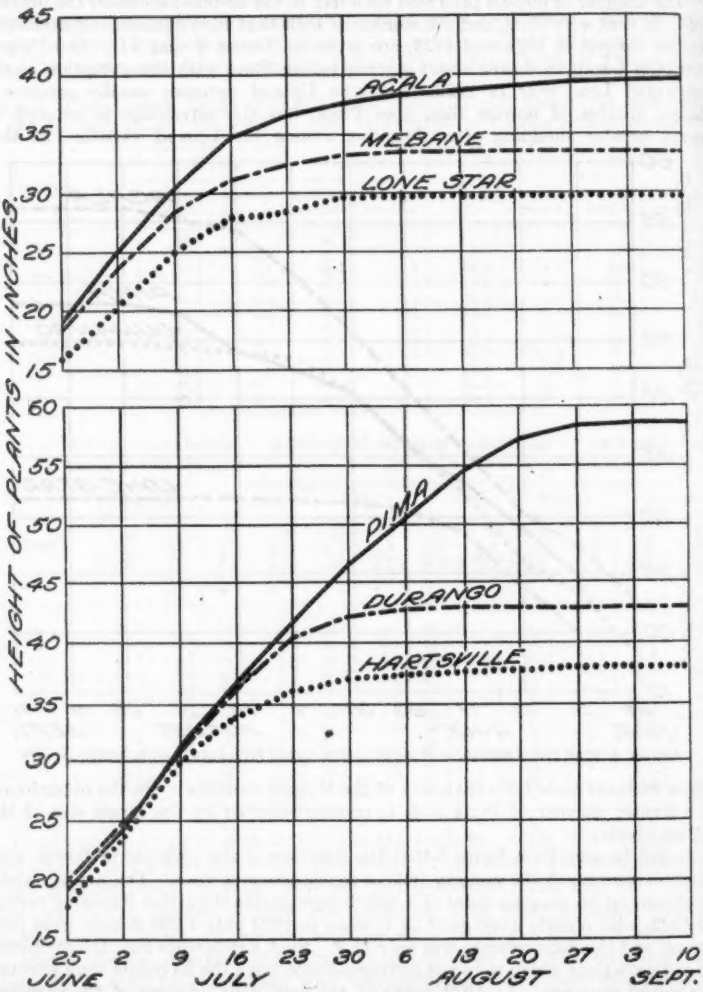


FIG. 2.—Average rate of growth for 25 plants in each variety from June 25 to September 10, 1923.

The period of active flowering is apparently closely related to the period of active growth of the plants, which is shown by comparing figure 3 with figures 1 and 2. Under the conditions of the experiment the short growing season of Lone Star was also reflected in the short flowering season, and the lengths of the flowering periods of the other varieties are also proportionate to the length of their respective growing seasons, except that flowering may cease through shedding of squares. The Pima plants, however, though they continued growing

later in the fall than the other varieties, had a shorter period of active flowering than Acala or Durango in 1922, and shorter than Acala or Hartsville in 1923. Occasional flowers appeared in all of the varieties after the regular flower counts were discontinued. It was noted that this casual flowering continued longer in Pima than in other varieties.

COMPARISON OF BOLL SHEDDING

Egyptian and Upland cottons differ considerably in susceptibility to shedding, both of squares and of young bolls. Shedding has been studied in Upland cotton by Lloyd (*4, 5*)[1], Ewing (*2*) and others in the United States, and in Egyptian cotton by Balls (*1*). Lloyd found in Alabama that about 50 per cent of the shedding in Upland varieties consisted of squares, but Ewing asserts that shedding in the square stage is relatively unimportant in Mississippi. Balls reports that "shedding in Egypt takes place almost entirely in the flower stage," probably

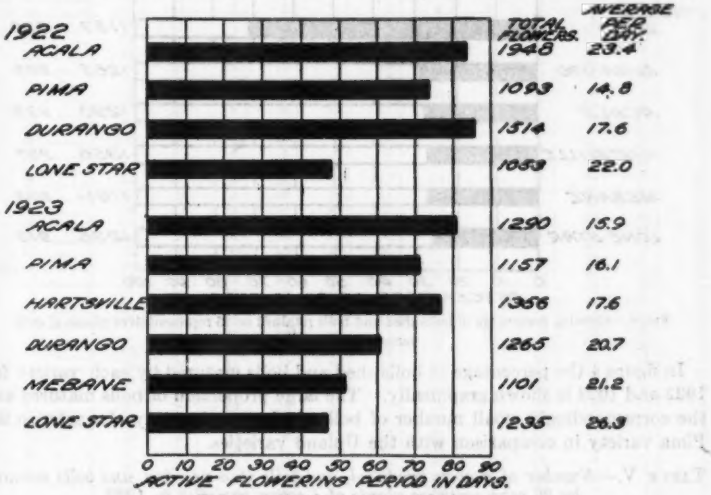


FIG. 3.—Active flowering period in days.

meaning 2 or 3 days after flowering. In Arizona it has been found that most of the shedding in both Egyptian and Upland varieties occurs soon after flowering, before the bolls are 10 days old. Under some conditions, however, the shedding of squares also becomes an important factor and causes reduction in yields.

Shedding data covering two seasons at Sacaton, Ariz., are contained in Tables V and VI. Pima cotton in 1922 retained 82.5 per cent of its bolls and in 1923 70.7 per cent, under conditions where Upland varieties usually retained less than 30 per cent of their bolls.

The greater ability to retain its squares and bolls enables the Pima Egyptian cotton to produce satisfactory yields in the Southwestern States, notwithstanding the smaller bolls. In some years the shedding of Pima bolls at Sacaton has been even less than in this experiment. In 1920 Martin and Loomis (*7*) reported a loss of only 11.2 per cent from a total of 10,317 flowers. Willett [2] recorded a loss of 15.8 per cent in 1922 from a total of 7,291 flowers. Other data on boll shedding in 1923 showed Pima at Sacaton retaining 86.4 per cent of the bolls, and Acala 30.5 per cent, while at Shafter, Calif., 90.2 per cent of Pima bolls were retained, and only 31 per cent of Acala bolls.

[1] Reference is made by number (italic) to "Literature cited," p. 953.

[2] Unpublished data communicated by Dr. T. H. Kearney. The data from Sacaton in 1923 were secured by Max Willett and Dow D. Porter, and those from Shafter by R. H. Peebles.

The data in Table VI show that the greatest amount of shedding of all varieties for both 1922 and 1923 occurred during the period from July 10 to August 20, when temperatures were highest and abrupt weather changes occurred.

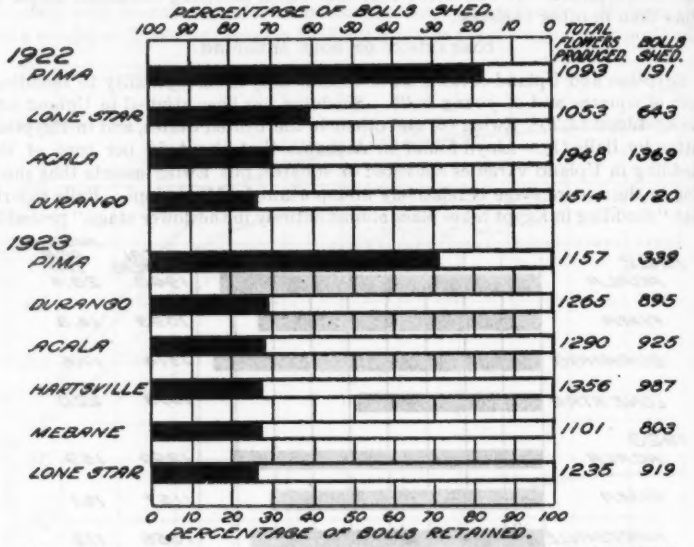


FIG. 4.—Showing percentage of bolls shed and bolls retained on 25 representative plants of each variety in 1922 and 1923

In figure 4 the percentage of bolls shed and bolls matured by each variety for 1922 and 1923 is shown graphically. The large proportion of bolls matured and the correspondingly small number of bolls shed, conspicuously characterize the Pima variety in comparison with the Upland varieties.

TABLE V.—*Number of flowers produced, and bolls shed per day, and bolls matured by 25 representative plants of 4 cotton varieties in 1922*

Date	Variety											
	Acala			Durango			Pima			Lone Star		
	Number flowers	Bolls shed	Mature bolls	Number flowers	Bolls shed	Mature bolls	Number flowers	Bolls shed	Mature bolls	Number flowers	Bolls shed	Mature bolls
June 22				3	3	0						
23	1	0	1	1	1	0						
24	1	1	0	1	1	0						
25	1	1	0	1	0	1						
26	1	0	1	2	1	1						
27	5	2	3	5	2	3						
28	4	1	3	2	2	0						
29	1	1	0	3	1	2	2	0	2			
30	8	4	4				2	0	2			
July 1	5	0	5	4	1	3	2	1	1			
2	6	3	3	2	2	0	1	0	1			
3	6	6	0	4	4	0	3	0	3			
4	10	4	6	3	2	1	4	1	3			
5	12	7	5	3	3	0	4	3	1			
6	22	18	4	13	11	2	6	0	6	2	1	1
7	20	12	8	13	9	4	2	0	2	3	3	0
8	19	10	9	7	4	3	8	1	7	4	3	1
9	34	17	7	15	12	3	11	0	11	2	1	1

TABLE V.—*Number of flowers produced and bolls shed per day, and bolls matured by 25 representative plants of 4 cotton varieties in 1922*—Continued

Date	Variety											
	Acala			Durango			Pima			Lone Star		
	Number flowers	Bolls shed	Mature bolls	Number flowers	Bolls shed	Mature bolls	Number flowers	Bolls shed	Mature bolls	Number flowers	Bolls shed	Mature bolls
July 10	24	18	6	13	9	4	8	1	7	1	1	0
11	15	11	4	8	8	0	9	1	8	1	1	0
12	31	24	7	11	6	5	3	1	2	*4	4	0
13	26	22	4	9	8	1	5	1	4	2	2	0
14	21	18	3	8	7	1	8	1	7			
15	16	12	4	5	2	3	7	0	7	5	3	2
16	30	19	11	28	14	14	7	0	7	17	2	15
17	24	16	8	10	8	2	6	1	5	14	1	13
18	29	23	6	17	7	10	8	0	8	20	8	12
19	24	17	7	12	7	5	3	0	3	24	8	16
20	11	10	1	10	6	4	8	2	6	16	5	11
21	31	23	8	24	13	11	10	3	7	43	17	26
22	37	28	9	15	10	5	12	3	9	29	18	11
23	28	22	6	11	8	3	7	1	6	18	13	5
24	15	14	1	8	8	0	10	2	8	33	21	12
25	35	29	6	21	13	8	16	6	10	51	44	7
26	34	25	9	22	11	11	14	0	14	42	32	10
27	32	27	5	33	19	14	21	2	19	65	50	15
28	38	24	14	35	27	8	16	0	16	53	28	25
29	28	21	7	26	20	6	10	0	10	50	28	22
30	24	14	10	31	25	6	18	1	17	46	14	32
31	28	19	9	35	22	13	12	1	11	54	24	30
Aug. 1	46	26	20	48	35	13	14	0	14	72	43	29
2	37	25	12	25	23	2	21	2	19	49	35	14
3	27	14	13	43	30	13	16	6	10	43	29	14
4	35	21	14	46	35	11	25	7	18	49	36	13
5	49	37	12	52	40	12	32	21	11	49	39	10
6	43	28	15	59	52	7	24	15	9	52	35	17
7	40	27	13	41	33	8	17	2	15	24	18	6
8	50	38	12	57	45	12	36	1	35	27	18	9
9	48	29	19	56	48	8	28	1	27	30	18	12
10	41	27	14	61	54	7	37	2	35	16	10	6
11	37	27	10	39	32	7	22	2	20	8	4	4
12	35	22	13	32	30	2	36	2	34	7	6	1
13	34	27	7	59	45	14	41	4	37	15	10	5
14	51	41	10	41	24	17	28	0	28	5	3	2
15	58	36	22	43	25	18	40	2	38	4	4	0
16	38	29	9	55	38	17	32	4	28	2	1	0
17	46	37	9	38	31	7	32	4	28	1	1	0
18	32	21	11	19	17	2	47	10	37			
19	34	28	6	27	25	2	24	7	17			
20	36	27	9	22	19	3	29	9	20			
21	33	23	10	16	16	0	40	11	29			
22	24	14	10	21	15	6	25	6	19	1	1	0
23	33	31	2	16	15	1	26	9	17			
24	36	31	5	13	12	1	13	7	6			
25	34	28	6	12	12	0	11	7	4			
26	19	18	1	8	7	1	3	3	0			
27	26	22	4	13	9	4	2	2	0			
28	31	29	2	9	7	2	3	2	1			
29	27	19	8	14	7	7						
30	17	14	3	18	4	14						
31	23	12	11	6	3	3						
Sept. 1	21	7	14	7	3	4						
2	10	5	5	3	1	2	5	1	4			
3	8	4	4	1	1	0	16	1	15			
4	16	8	8	2	1	1	13	3	10			
5	5	2	3				6	1	5			
6	8	3	5	2	0	2	7	1	6			
7	6	3	3	3	3	0	26	0	26			
8	7	3	4	4	3	1	8	0	8			
9	4	1	3	1	1	0	8	1	7			
10	5	1	4				5	0	5			
11	3	0	3				11	1	10			
12	4	1	3	3	1	2	11	1	10			
13	3	0	3	4	1	3	7	0	7			
14	1	0	1				3	0	3			
15				1	0	1						
Total	1,948	1,369	579	1,514	1,120	394	1,093	191	902	1,053	643	410
Per cent shed		70.3			74			17.5			61.2	

TABLE VI.—*Number of flowers produced and bolls shed per day, and number of bolls matured by 25 representative plants of six cotton varieties in 1923*

Date	Hartsville			Durango			Pima			Acala			Mebane			Lone Star		
	Flowers	Bolls shed	Bolls retained	Flowers	Bolls shed	Bolls retained	Flowers	Bolls shed	Bolls retained	Flowers	Bolls shed	Bolls retained	Flowers	Bolls shed	Bolls retained	Flowers	Bolls shed	Bolls retained
June [27				1	1	0				1	0	1	1	0	1			
28				1	0	1				0	0	0	2	1	1			
29				4	0	4				3	0	3	7	2	5	1	1	0
30	1	0	1	3	1	2				4	1	3	5	2	3	2	2	0
July 1	1	0	1	4	0	4				8	1	7	3	1	2	5	4	1
2	2	0	2	5	1	4				6	3	3	10	8	2	6	4	2
3	5	2	3	8	3	5				5	2	3	6	6	0	4	1	3
4	7	3	4	3	1	2				9	7	2	8	5	3	6	3	3
5	7	4	3	9	0	9				7	1	6	15	11	4	3	1	2
6	12	6	6	3	1	2	2	1	1	5	2	3	15	9	6	7	7	0
7	13	4	9	6	0	6	4	1	3	8	3	5	20	13	7	7	1	6
8	12	4	8	7	5	2	11	2	9	16	3	13	5	4	1	10	4	6
9	14	5	9	2	1	1	1	0	1	14	12	2	18	6	12	12	2	10
10	14	6	8	12	6	6	10	0	10	22	8	14	14	7	7	27	9	18
11	26	12	14	8	5	3	8	1	7	21	12	9	29	21	8	19	9	10
12	21	7	14	19	14	5	9	0	9	14	10	4	26	21	5	17	9	8
13	40	26	14	13	9	4	17	3	14	39	31	8	52	42	10	49	30	19
14	27	9	18	21	14	7	19	1	18	36	31	5	33	24	9	35	24	11
15	29	20	9	13	9	4	17	1	16	20	15	5	33	31	2	25	22	3
16	35	20	15	29	25	4	17	1	16	32	24	8	45	42	3	46	40	6
17	38	28	10	26	20	6	16	1	15	32	27	5	39	35	4	26	22	4
18	45	32	13	21	16	5	29	4	25	35	23	12	28	24	4	48	37	11
19	25	18	7	27	20	7	12	4	8	23	16	7	50	39	11	49	41	8
20	51	38	13	50	20	30	26	2	24	52	37	15	63	45	18	54	44	10
21	37	28	9	21	11	10	21	4	17	39	24	15	44	18	26	43	22	21
22	39	28	11	20	9	11	29	6	23	53	22	31	43	20	23	58	23	35
23	46	32	14	31	16	15	31	1	30	50	26	24	42	23	19	55	34	21
24	34	28	6	27	21	6	20	4	16	48	39	9	46	21	25	73	47	26
25	45	37	8	34	25	9	36	7	29	54	42	12	43	31	12	57	51	6
26	50	39	11	46	31	15	22	5	17	70	61	9	52	45	7	65	65	0
27	49	38	11	40	34	6	25	7	18	48	44	4	20	19	1	50	49	1
28	40	33	7	40	33	7	23	6	17	47	46	1	38	29	9	48	44	4
29	37	33	4	30	28	2	20	7	13	46	40	6	35	33	2	56	44	12
30	40	33	7	48	42	6	17	3	14	43	38	5	26	22	4	42	41	1
31	45	36	9	42	36	6	25	11	14	41	40	1	27	25	2	46	36	10
Aug. 1	57	47	10	54	49	5	23	8	15	45	42	3	28	28	0	30	30	0
2	47	38	9	63	57	6	38	13	25	50	49	1	35	33	2	47	47	0
3	41	32	9	44	31	13	30	12	18	47	43	4	16	16	0	30	28	2
4	48	39	9	36	20	16	27	10	17	32	21	11	15	13	2	19	17	2
5	33	23	10	29	15	14	19	8	11	34	17	17	12	6	6	17	9	8
6	35	30	5	47	16	31	21	8	13	19	7	12	12	1	11	9	5	4
7	21	13	8	31	10	21	27	8	19	16	6	10	8	3	5	12	2	10
8	26	22	4	37	21	16	24	6	18	12	5	7	4	2	2	5	3	2
9	19	18	1	45	42	3	25	19	6	16	16	0	7	5	2	4	3	1
10	13	12	1	29	23	6	21	8	13	4	4	0	0	0	0	2	0	2
11	23	22	1	34	30	4	32	15	17	11	9	2	4	3	1	2	1	1
12	7	6	1	14	14	0	11	5	6	3	1	2	0	0	0	0	0	0
13	20	17	3	32	28	4	13	4	15	6	5	1	4	3	1	1	0	1
14	10	9	1	20	19	1	20	4	16	3	2	1	2	2	0	2	1	1
15	9	9	0	10	8	2	21	4	17	3	3	0	0	0	0	0	0	0
16	6	6	0	11	11	0	15	5	10	4	1	3	2	2	0	0	0	0
17	7	7	0	13	13	0	21	7	14	1	0	1	2	1	1	0	0	0
18	8	8	0	14	11	3	33	8	25	2	0	2	0	0	0	0	0	0
19	6	6	0	6	3	3	15	3	12	3	3	0	0	0	0	0	0	0
20	0	0	0	9	7	2	16	2	14	1	0	1	0	0	0	0	0	0
21	5	4	1	8	5	3	17	5	12	0	0	0	0	0	0	0	0	0
22	5	2	3	0	0	0	19	7	12	0	0	0	0	0	0	0	0	0
23	1	1	0	2	2	0	15	5	10	0	0	0	0	0	0	0	0	0
24	4	3	1	2	1	1	12	5	7	0	0	0	2	0	2	0	0	0
25	1	1	0	0	0	0	7	4	3	0	0	0	1	0	1	0	0	0
26	1	0	1	1	1	0	20	7	13	0	0	0	0	0	0	0	0	0
27	0	0	0				17	9	8	1	0	1	0	0	0	0	0	0
28	0	0	0				11	9	2	0	0	0	0	0	0	0	0	0
29	0	0	0				7	3	4	1	0	1	0	0	0	0	0	0
30	0	0	0				8	2	6	0	0	0	0	0	0	0	0	0
31	0	0	0				11	5	6	2	0	2	0	0	0	1	0	1
Sept. 1	1	0	1				11	6	5	0	0	0	0	0	0	0	0	0
2	2	0	2				8	4	4	1	0	1	0	0	0	0	0	0
3	1	0	1				8	2	6	5	0	5	1	0	1	2	0	2
4	3	0	3				4	0	4	0	0	0	0	0	0	0	0	0
5	1	1	0				7	5	2	0	0	0	0	0	0	0	0	0
6	3	0	3				10	3	7	1	0	1	0	0	0	0	0	0
7	1	0	1				7	4	3	1	0	1	0	0	0	0	0	0
8	0	0	0				3	0	3	0	0	0	0	0	0	0	0	0

TABLE VI.—*Number of flowers produced and bolls shed per day, and number of bolls matured by 25 representative plants of six cotton varieties in 1923*—Continued

Date	Hartsville			Durango			Pima			Acala			Mebane			Lone Star		
	Flowers	Bolls shed	Bolls retained	Flowers	Bolls shed	Bolls retained	Flowers	Bolls shed	Bolls retained	Flowers	Bolls shed	Bolls retained	Flowers	Bolls shed	Bolls retained	Flowers	Bolls shed	Bolls retained
Sept. 9	2	1	1	----	----	----	8	3	5	5	0	5	0	0	0	0	0	0
10	1	0	1	----	----	----	5	1	4	0	0	0	1	0	1	0	0	0
11	0	0	0	----	----	----	3	2	1	2	0	2	0	0	0	0	0	0
12	0	0	0	----	----	----	2	0	2	1	0	1	0	0	0	0	0	0
13	0	0	0	----	----	----	6	4	2	0	0	0	0	0	0	0	0	0
14	1	1	0	----	----	----	3	1	2	3	0	3	2	0	2	0	0	0
15	----	----	----	----	----	----	3	3	0	4	0	4	----	----	----	1	0	1
Total flowers		1,356			1,265			1,157			1,290			1,101			1,235	
Total bolls shed		987			895			339			925			803			919	
Bolls retained		369			370			818			365			298			316	
Per cent shed		72.8			70.8			29.3			71.7			72.9			74.4	

TABLE VII.—*Showing number of days after flowering at which bolls shed at the United States Field Station, Sacaton, Ariz., in 1922 and 1923*

Number of days after flowering	1922				1923					
	Variety				Variety					
	Acala	Durango	Pima	Lone Star	Acala	Durango	Pima	Lone Star	Hartsville	Mebane
1	1	4	4	2	5	2	----	4	3	7
2	9	32	----	3	16	11	2	10	9	10
3	41	60	----	16	36	36	14	17	29	13
4	101	94	2	29	97	81	17	73	60	54
5	251	186	12	83	134	158	39	128	126	110
6	319	186	16	142	169	165	37	159	190	148
7	284	199	15	124	169	132	30	183	200	172
8	166	119	16	110	85	81	31	120	130	165
9	74	64	10	46	47	64	21	66	73	38
10	32	52	18	36	44	38	21	48	44	43
11	31	36	13	11	32	25	10	23	22	20
12	16	27	12	14	20	21	22	15	25	11
13	12	14	13	6	20	21	13	16	13	13
14	5	19	9	5	11	7	9	10	13	10
15	5	8	6	2	4	14	13	8	8	5
16	3	7	4	6	6	6	13	3	4	3
17	5	6	6	----	7	2	7	4	17	5
18	3	2	1	1	2	9	4	6	----	2
19	2	2	4	1	4	3	4	2	6	1
20	1	3	3	1	4	5	5	5	1	2
Mean age at which bolls shed	6.7	6.9	10.1	7.2	7.0	7.2	9.1	7.3	7.3	7.2

Data for two seasons on the number of bolls shed each day from the first to the twentieth day after flowering are shown in Table VII. While a few bolls were shed more than 20 days after flowering this was due to bollworm injury and is not included in the above table. Martin and Loomis found that with Pima cotton in Arizona the greatest shedding of bolls occurred between 4 and 14 days after flowering. It will be seen from Table VII that the average age at which bolls of the Upland varieties shed was about 7 days, while the average age at which Pima bolls shed was about 10 days in 1922 and 9 days in 1923.

TABLE X.—*Showing the varietal differences in length of boll development period of 6 varieties of cotton grown under conditions obtaining at the United States Field Station, Sacaton, Ariz., in 1923*

5-day periods (flower dates)	Mean number of days from flower to open boll					
	Hartsville	Durango	Pima	Acala	Mebane	Lone Star
June 27 to July 2	48.5±0.71	47.0±0.29	.....	48.1±0.30	48.3±0.32	47.3±0.80
July 3 to July 7	53.3± .47	47.4± .27	45.7±0.66	50.9± .58	50.2± .67	49.5± .71
July 8 to July 12	51.5± .19	46.4± .44	49.7± .47	48.5± .18	48.6± .22	49.2± .16
July 13 to July 17	50.8± .20	44.8± .45	53.6± .22	47.9± .52	48.2± .39	47.7± .26
July 18 to July 22	53.1± .23	45.7± .22	54.7± .24	48.5± .20	50.3± .30	50.3± .24
July 23 to July 27	52.7± .17	44.8± .22	57.0± .24	50.4± .31	49.6± .33	51.8± .22
July 28 to Aug. 1	54.8± .41	45.5± .28	57.5± .21	50.7±1.09	49.5± .77	52.0± .00
Aug. 2 to Aug. 6	57.4± .45	47.7± .33	60.8± .25	51.5± .33	54.4±1.12	54.2± .47
Aug. 7 to Aug. 11	59.2±1.18	47.4± .58	64.6± .25	56.6± .79	54.4±1.09	58.1±1.42
Aug. 12 to Aug. 16	61.0±1.91	52.0± .80	68.3± .33	60.8±1.66	59.0± .00	.....
Aug. 17 to Aug. 21	63.0± .00	53.0± .82	72.6± .45	.....	.....	.....
Aug. 22 to Aug. 26	69.0± .68	.....	79.7± .69	.....	.....	.....
Aug. 27 to Aug. 31	.....	.....	83.3± .41	75.5± .79	.....	.....
Sept. 1 to Sept. 5	71.3±2.46	.....	85.5± .01	74.8±1.32	.....	.....
Sept. 6 to Sept. 10	.....	.....	90.7± .86	79.0± .00	.....	.....

THE PERIODS OF BOLL DEVELOPMENT

Table X shows the mean number of days from flower to open boll of flowers produced from June 27 to August 31, grouped in five-day periods. It will be noted that in all varieties except Pima the boll development period was shorter for flowers that opened between July 13 and July 17, than for the periods immediately preceding and immediately following. This undoubtedly was due to the fact that the plants suffered from lack of moisture for a few days about September 1 to 4, causing some of the bolls to open prematurely. The Pima plants did not suffer, and the bolls did not show the reduced period of development.

Another decline in the boll development period, which also is probably due to a period of water shortage, is noticeable in the Hartsville, Durango, and Mebane varieties in bolls produced from flowers that opened between July 23 and July 27. If this interpretation is correct, such recording of the periods of boll development would be of use in cultural experiments in determining the conditions of growth, and whether sufficient irrigation water had been applied. The gradual lengthening of the boll development period as the season advances is in agreement with the results reported by King (*3*), Martin and Loomis (*7*), and Martin, Ballard, and Simpson (*6*). The mean period of boll development of the six varieties for the season of 1923 are shown in Table X.

COMPARISONS OF YIELDS

The cotton growers in the Salt River Valley are confronted with the problem of choosing the variety that will yield the largest returns under their conditions. In order to meet the higher fixed charges of irrigated farming and the higher cost of harvesting the cotton crop in this region, a larger return per acre must be assured than is necessary in the greater part of the cotton belt. The returns per acre derived from Pima cotton during the years 1916 to 1919, when it was the only variety grown, were undoubtedly greater than could have been secured from any other variety. In recent years, however, the market conditions have favored the Upland varieties, though opinion is much divided as to which Upland variety is the best for their purposes. Though the question turns largely upon the yields in the present state of the market it is recognized that premiums can be secured for Upland staples of good quality, and that it is desirable to unite upon a single Upland variety in order to develop local supplies of good seed.

TABLE IX.—*Yield of seed cotton of the varieties compared in 1920, 1921, 1922, and 1923 at the United States Field Station, Sacaton, Ariz., given in pounds and by rows, and the total per plot*

Row numbers	1920			1921			
	C2-13 Pima	C2-14 Durango	C2-15 Lone Star	C2-12 Pima	C2-14 Durango	C2-15 Lone Star	C2-13 Acala
1	64.8	52.5	59.5	80.6	39.5	61.8	61.1
2	63.1	51.1	66.4	78.5	28.6	57.4	64.3
3	74.4	49.7	64.2	78.7	20.2	66.9	67.8
4	59.3	47.9	63.7	66.1	24.6	61.7	64.1
5	63.6	46.0	64.4	67.2	22.7	67.7	65.0
6	72.5	49.4	64.4	65.1	22.6	65.8	76.7
7	58.8	63.7	58.3	62.9	34.1	78.1	79.4
Total	456.6	360.3	440.8	499.1	192.3	459.4	478.4

Row numbers	1922				1923					
	C2-14 Pima	C2-13 Durango	C2-15 Lone Star	C2-12 Acala	C2-11 Pima	C2-10 Durango	C2-14 Lone Star	C2-12 Acala	C2-9 Hartsville	C2-13 Mebane
1	88.5	59.3	48.4	62.8	80.5	70.6	71.4	91.2	77.3	78.1
2	69.8	54.4	58.2	58.4	85.0	82.1	84.4	83.8	81.8	74.4
3	70.8	57.6	48.2	58.0	86.1	82.6	81.0	80.0	77.3	83.6
4	64.2	45.9	47.7	59.6	82.7	85.6	93.7	90.5	78.7	95.5
5	70.4	57.7	48.9	60.8	81.8	72.3	106.3	80.4	76.6	88.3
6	65.8	53.0	46.4	60.6	95.0	92.0	87.9	90.8	90.7	84.8
7	82.9	58.0	55.7	51.6	80.8	92.6	64.5	84.8	94.3	92.9
Total	512.4	385.9	353.5	411.8	591.9	577.8	589.2	601.5	576.7	597.6

It will be observed in Table IX that Pima led all other varieties in yield during the first three years of the test. In 1923, a season which was very favorable for the production of all kinds of cotton, the Pima variety was third in rank from the standpoint of total production, though the differences were not significant in view of the wide variations between the individual rows.

The comparatively high yielding capacity of the Pima variety in some of the valleys of the Southwestern States is explained by the ability of this type of cotton plant to retain under normal conditions from 70 to 90 per cent of the total bolls produced. By referring to the data on shedding in Tables V and VI, and to figure 4, it will be seen that the Pima plants were able to retain and mature over 40 per cent more of the bolls than the best adapted Upland varieties grown under similar conditions in 1922 and 1923.

While the total yields of seed cotton have been larger for the Acala than for other Upland varieties during the three years in which this variety has been included in the comparison, the differences in row yields are so large that the totals may not be significant.

Greater irregularities appear in the yields of Durango and Lone Star than in those of Pima and Acala, and also wider variations in the rates of shedding. Such fluctuations may indicate a lack of stability in these varieties, as though less adapted than Pima and Acala to withstand the extremes of the summer climate.

In 1922 the behavior of the Acala and Hartsville varieties in late plantings was compared at Sacaton. For another purpose a very late planting of Acala was made, on June 22, at the side of a Hartsville planting on June 5. Even with this handicap of more than two weeks the Acala rows were nearly as productive as the Hartsville, as shown in Table X. In 1923 the two varieties were compared at different dates of planting, April 30 and May 20. The soil where these plant-

ings were made, in both 1922 and 1923, was somewhat impervious to irrigation water and impregnated with alkali, thus representing rather unfavorable conditions for crop production. The yields obtained in both years are given in Table X.

TABLE X.—*Comparative yields of late planted Acala and Hartsville cotton varieties in 7-row plats at the United States Field Station, Sacaton, Ariz., in 1922 and 1923*

Row No.	1922		1923			
	Date planted		Date planted			
	June 22, Acala	June 5, Hartsville	Apr. 30, Acala	Apr. 30, Hartsville	May 20, Acala	May 20, Hartsville
	Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
1	16.1	14.4	21.3	12.7	29.4	16.5
2	12.7	14.0	27.5	17.0	28.3	16.9
3	13.6	15.1	24.6	19.1	32.4	22.2
4	----------	17.3	24.1	19.8	25.8	23.0
5	----------	14.1	22.9	29.8	31.8	23.0
6	----------	15.1	24.0	31.7	21.6	18.2
7	----------	7.4	22.8	24.6	27.9	13.4
Mean	14.13	13.91	23.90	22.1	28.17	19.07

BOLL, LINT, AND SEED CHARACTERS

Table XI shows data on the size of bolls of the varieties grown at Sacaton in 1923, as computed from three 20-boll samples of each variety. The figures give the number of bolls necessary to make a pound of seed cotton and the number of bolls necessary to make a pound of lint. A count was also made to determine the proportion of 3-, 4-, and 5-lock bolls produced by the different varieties. The Pima variety produced 91.8 per cent 3-lock bolls, 8.2 per cent 4-lock bolls, and no 5-lock bolls. Of the Upland varieties, Lone Star had 73.9 per cent 5-lock bolls, Mebane 72, Hartsville 64.3, Acala 54.4, and Durango 50 per cent.

TABLE XI.—*Size of bolls, Sacaton, Ariz., 1923*

Variety	Number of bolls per pound of seed cotton	Number of bolls per pound of lint cotton
Hartsville	60	234
Durango	76	266
Pima	122	451
Acala	63	200
Mebane	56	167
Lone Star	50	144

Table XII shows the variation which occurred in the lint percentage, lint index, and seed index for the different pickings. These figures are means of 20 representative samples from each picking. With all varieties except Hartsville the lowest lint percentage was obtained in the last picking. These figures show a tendency for both the lint index and the seed index to become lower toward the end of the season.

From Tables XI and XII it appears that Lone Star had larger bolls as well as a higher lint percentage and a higher lint index than any other variety, while the Pima had the smallest bolls and the lowest lint index. The largest seeds and the lowest percentage of lint were in Hartsville.

TABLE XII.—*Lint and seed data of five pickings as obtained from means of 20 samples from each picking, 1923*

Variety	Lint percentage				
	Mean first picking	Mean second picking	Mean third picking	Mean fourth picking	Mean fifth picking
Hartsville	28.1±.07	28.0±.24	25.3±.16	26.5±.15	26.7±.18
Durango	31.9±.10	31.0±.32	30.0±.08	32.3±.14	29.5±.17
Pima	28.2±.07	27.4±.07	28.5±.08	26.4±.15	----------
Acala	34.4±.13	32.5±.12	31.8±.13	33.1±.18	30.9±.21
Mebane	36.0±.15	35.9±.10	34.9±.11	35.7±.11	32.0±.23
Lone Star	36.4±.08	35.7±.07	35.4±.11	36.2±.13	32.4±.18

Variety	Lint index[a]				
Hartsville	6.37±.04	6.18±.04	5.59±.10	5.79±.05	5.56±.05
Durango	6.27±.04	6.26±.09	6.01±.04	6.00±.03	5.51±.05
Pima	5.46±.02	5.24±.03	5.50±.03	4.90±.06	----------
Acala	7.20±.07	6.71±.03	6.46±.04	6.50±.03	5.75±.07
Mebane	8.03±.06	7.95±.06	7.38±.04	7.58±.07	6.31±.07
Lone Star	8.62±.04	8.23±.06	8.29±.05	7.89±.07	6.71±.09

Variety	Seed index[b]				
Hartsville	16.3±.10	15.9±.14	16.4±.11	16.1±.10	15.3±.09
Durango	13.4±.12	14.0±.12	14.0±.10	12.6±.10	13.1±.10
Pima	13.9±.04	13.8±.07	13.8±.04	13.7±.08	----------
Acala	13.7±.08	13.9±.08	13.9±.10	13.1±.09	12.9±.11
Mebane	14.3±.07	14.2±.13	13.8±.09	13.8±.07	13.4±.06
Lone Star	15.1±.05	14.9±.09	15.1±.09	13.9±.11	14.0±.14

[a] Weight of lint from 100 seeds. [b] Weight of 100 seeds.

Fertile soils combined with the high temperatures which prevail over a long period, and the ample supplies of irrigation water which are usually available, often produce large, vigorous plants, with long branches and dense foliage, so that cultural precautions may be necessary to avoid too rapid and luxuriant growth. Larger yields are usually obtained from fields where the plants are 4 or 5 feet high rather than from taller plants. For good results the growth must be gradual and continuous instead of rapid and intermittent.

It is characteristic of Pima cotton to produce a strong upright central stalk with few vegetative branches and comparatively long fruiting branches, with long internodes and open foliage, which render it well adapted for conditions obtaining in irrigated regions (Pl. 1, A). Damage seldom results from lodging or breaking down of the plants unless they are extremely rank and widely spaced, so that the vegetative branches or side stalks grow large and are weighted with bolls.

The strong central stalk and upturned leaves are advantages of the Hartsville variety, though many growers would not consider an Upland cotton with a low percentage of lint (Pl. 1, B).

Durango, because of its upright habit of growth and strong, stiff central stalk, and rather narrow, deeply lobed leaves, has some advantages over the lower and more compact types of Upland cottons for growing under irrigation conditions (Pl. 1, C). Though over-rank Durango fields may be badly tangled, they are seldom lodged as flat on the ground as the Texas big-boll varieties. A tendency to excessive shedding under adverse conditions is responsible for occasional low yields as in the season of 1921 at Sacaton.

The Acala variety is somewhat like Durango in habits of growth, but usually with shorter stalks and less tendency to the "cluster" habit of short fruiting branches. The central stalk is fairly strong and the plants seldom become completely prostrate late in the season, even when heavily loaded with bolls (Pl. 1, D). Its ability to set bolls rapidly and to mature large crops under short-season conditions or when planted very late are important features.

The Lone Star and Mebane (Pl. 2, A and B) varieties representing the Texas big-boll type are very similar in their habits of growth, being lower and more compact than the preceding varieties, but with rather long spreading vegetative branches, short jointed stalks, large leaves and bolls. While these varieties often produce large yields under irrigated conditions, they frequently present difficulties in picking on account of the rather weak and flexible stalks which often lodge badly, so that many of the bolls lie on the ground where they may be mildewed or rotted, or the fiber stained by contact with soil.

Plats of the Pima, Hartsville, and Acala varieties are shown in Plate 3, A, B, C.

The average height of the 25 plants of each variety in 1923 which is shown in Table V represents fairly closely the relative height which plants of these varieties attain when grown on moderately fertile soils under irrigation.

SUMMARY

Adjacent plantings of Pima Egyptian and several Upland varieties of cotton were made at Sacaton, Ariz., from 1920 to 1923, and data of plant behavior secured on habits of growth, flowering, shedding, yields, and lint and boll characters. A series of measurements on selected groups of 25 plants of each variety were conducted through the seasons of 1922 and 1923.

From these data it appears that the active growing and flowering periods of the Lone Star and Mebane varieties were much shorter than those of Pima, Hartsville, Durango, or Acala. The Pima plants continued growth over a longer period than any other variety, but in 1922 and 1923 had a somewhat shorter period of flower production than some of the Upland varieties.

The Upland varieties began flowering and fruiting earlier, and produced a greater number of flowers during the season than the Pima variety, but on account of more extensive shedding among the Upland varieties they brought fewer bolls to maturity. In 1922 the 25 plants of Acala produced a total of 1,948 flowers, which was the greatest number recorded for any variety, but only 579 bolls were retained, whereas 25 Pima plants produced 1,093 flowers, of which 902 became mature bolls.

The highest shedding rate, 74.4 per cent, was recorded for Lone Star in 1923, while the lowest rate was for Pima, in 1922, which shed only 17.5 per cent of the young bolls.

The low shedding rate of Pima enabled that variety to produce yields which compared favorably with those of Upland cotton, notwithstanding the more abundant flowering and larger bolls of the Upland varieties.

The average age at which bolls of the Upland varieties shed was about 7 days, while the average age of shedding for Pima bolls was 10 days in 1922 and 9 days in 1923.

The longest mean period of boll development recorded was 62.3 days, which was required by bolls developed from flowers of Pima cotton produced from July 6 to September 10, 1923. The shortest mean period was 47.1 days, which was recorded for Durango bolls developed from flowers produced from June 29 to August 21. The mean periods required for bolls of four other Upland varieties were Hartsville 54.3, Acala 51.5, Mebane 50.5, and Lone Star 51.0 days.

The Pima variety produced higher yields of seed cotton than any of the Upland varieties included in the test during the first three years. In 1923 there was no material difference in the yields of the varieties. The highest yield, 2,406 pounds of seed cotton per acre, was produced by Acala, followed by Mebane with 2,390 pounds, and by Pima with 2,368 pounds per acre.

Acala cotton produced somewhat higher yields than Hartsville when late plantings of the two varieties were compared in alternate plats.

By obtaining the weights of three representative samples of 20 bolls each from the different varieties it was determined that only 50 bolls of Lone Star cotton were required to make a pound of seed cotton, whereas 122 bolls of Pima were required. The number of bolls of Hartsville, Durango, Acala, and Mebane required to make a pound were 60, 76, 63, and 56, respectively.

Examinations of representative samples of the several varieties showed a range of lint percentages from 25 to 36 in the Upland varieties and from 26 to 28 in Pima. The lowest percentages were in Hartsville and the highest in Lone Star. The lint index or weight of fiber from 100 seeds was lowest in Pima and highest in Lone Star.

The strong central stalks and upright habits of the Pima, Hartsville, Durango, and Acala varieties are recognized as advantages in irrigated regions, where damage to bolls and difficulties in picking are often caused by the "lodging" or prostration of plants of varieties with lower and more spreading habits of growth, as Mebane and Lone Star.

LITERATURE CITED

(1) Balls, W. L.
1912. The cotton plant in Egypt, studies in physiology and genetics. 202 p., illus. London.

(2) Ewing, E. C.
1918. A study of certain environmental factors and varietal differences influencing the fruiting of cotton. Miss. Agr. Exp. Sta. Tech. Bul. 8, 93 p.

(3) King, C. J.
1922. Water-stress behavior of Pima cotton in Arizona. U. S. Dept. Agr. Bul. 1018, 24 p., illus.

(4) Lloyd, F. E.
1916. The abscission of flower-buds and fruits in Gossypium, and its relation to environmental changes. Trans. Roy. Soc. Canada (III) 10 (IV): 55–61.

(5) ———
1920. Environmental changes and their effect upon boll-shedding in cotton. Ann. N. Y. Acad. Sci. 29: 1–131, illus.

(6) Martin, R. D., Ballard, W. W., and Simpson, D. M.
1923. Growth of fruiting parts in cotton. Jour. Agr. Research 25: 195–208, illus.

(7) ——— and Loomis, H. F.
1923. Summer irrigation of Pima cotton. Jour. Agr. Research 23: 927–946.

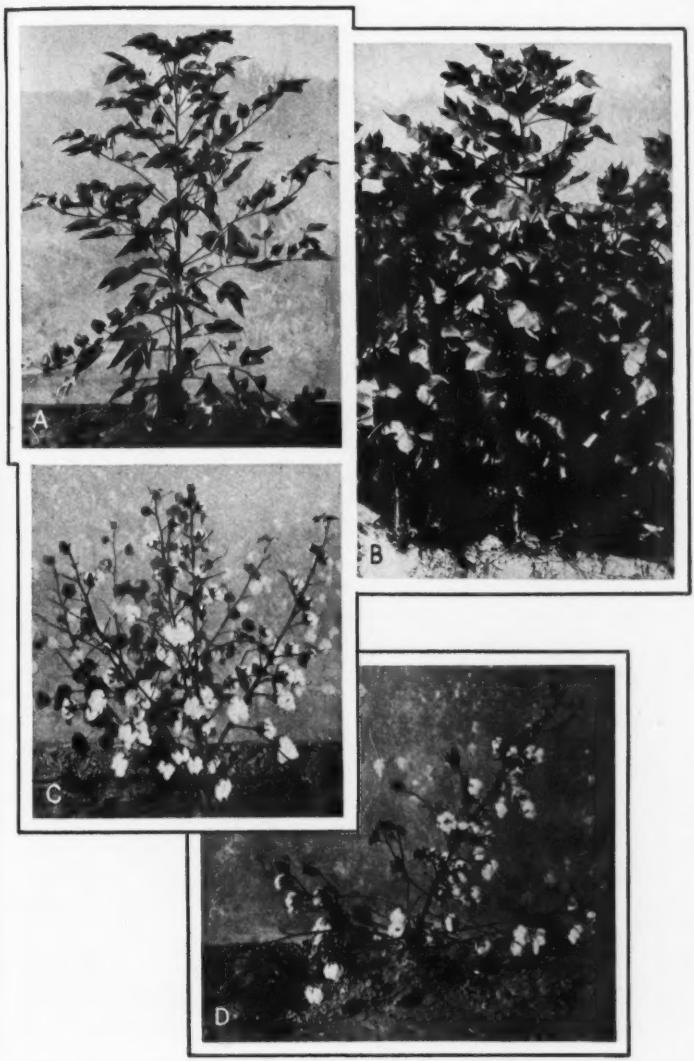
PLATE 1

A.—An ideal Pima cotton plant grown at Sacaton, Ariz. Note the upright habit, scarcity of vegetative branches, scant leaf covering and long prolific fruiting branches, which make this variety well adapted to the irrigated regions.

B.—Typical Hartsville cotton plant grown under irrigation conditions in the Southwest. Note the stiff upright habit of central stalk and vegetative branches. These are recognized as advantages under irrigation conditions.

C.—Defoliated Durango cotton plant grown under irrigated conditions in the Southwest. Note the stiff upright habit of central stalk and vegetative branches.

D.—Defoliated Acala cotton plant grown under irrigation conditions.


A
B
C
D

A
B

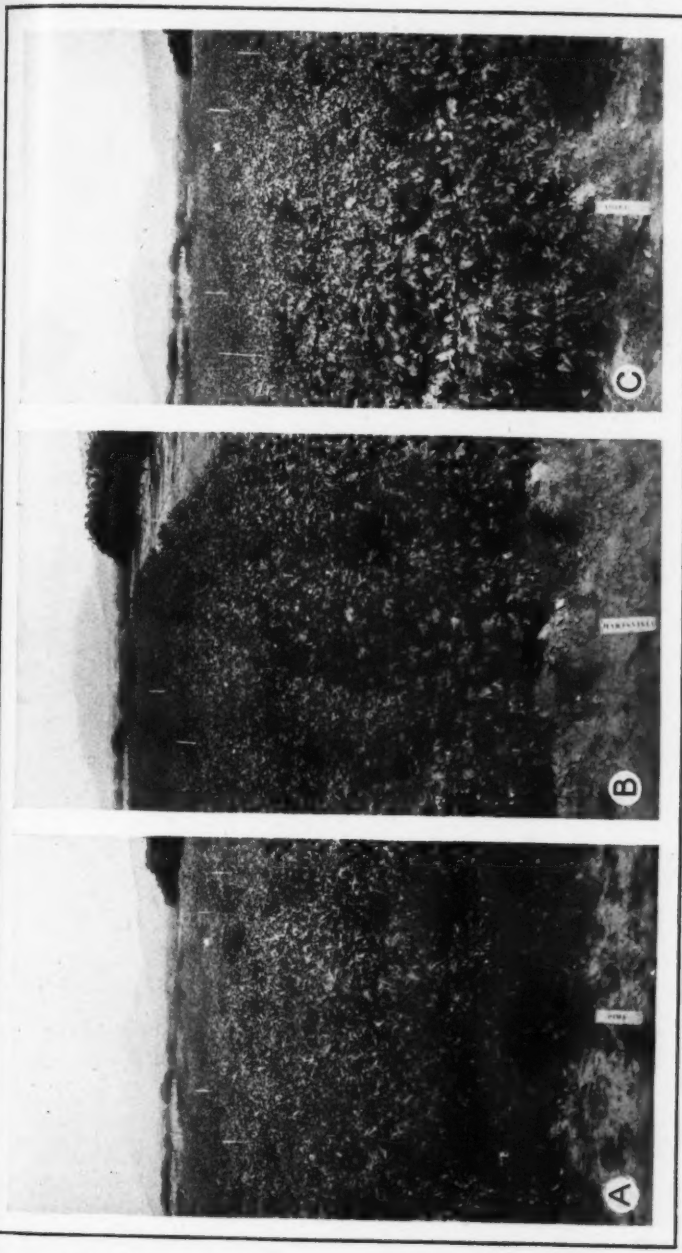
PLATE 2

A.—Lone Star cotton plant grown under irrigation conditions in the Southwest. Some of the bolls on the low limbs are often damaged in late season from being in contact with the wet soil.

B.—Plant of Mebane cotton prostrated from weight of bolls late in the season. The tendency of this and other varieties with low growth habits to "lodge" when grown on heavy soils is regarded as a serious disadvantage for growing in irrigated regions.

PLATE 3

A.—Plat of Pima cotton at Sacaton, Ariz., in 1923.
B.—Plat of Hartsville cotton at Sacaton, Ariz., in 1923.
C.—Plat of Acala cotton at Sacaton, Ariz., in 1923.


C
B
A

THE FUNGUS CAUSING THE COMMON BROWN ROT OF FRUITS IN AMERICA[1]

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Since investigators of the fungus causing the disease of fruits in the United States commonly referred to as "brown rot" have bestowed upon it several specific names, it seems worth while to determine, if possible, which name should be retained as the correct one. For many years the scientific name was generally accepted as *Oidium fructigenum* and later as *Monilia fructigena*, the American fungus being considered identical with the supposed single form of Europe, then passing under these names. As early as 1893 Schröter (*11*, *p. 67*)[2] by analogy had referred *Monilia fructigena* to the genus Sclerotinia, though he had not found an ascogenous stage and had no knowledge of its existence. Woronin (*15*) in 1900 showed that *Sclerotinia fructigena* is different from *S. cinerea*, the conidial stage of which was described by Bonorden (*2*, *p. 76*) in 1851 as *Monilia cinerea* and also referred to the genus Sclerotinia by Schröter (*11*, *p. 67*) in 1893. Since Woronin's conclusions were not immediately accepted, most investigators continued to use the name *Monilia fructigena* for the so-called brown rot fungus. After Norton (*7*) in 1902 proved that the species of Monilia causing the common brown rot of the peach in the United States is a conidial stage of a species of Sclerotinia, the name *Sclerotinia fructigena* came into general use. Later when Aderhold and Ruhland (*1*), Matheny (*6*), Conel (*3*), and other workers showed that the form common in America is not *Sclerotinia fructigena* but closely resembles and probably is identical with *S. cinerea*, the latter name became the one commonly accepted. Wormald (*13*), while studying the American and European forms, found that there were races or strains in *S. cinerea*. The American form being different from any of his European strains, he named it *Sclerotinia cinerea* forma *americana*.

Wormald (*13*) working with 13 strains of the American form found them to fruit more readily than the strains occuring in Britain and to show other slight differences when grown on artificial culture media. A constant but slight morphological difference was found in the conidial germ tubes. In the American strains these are at least 200 microns long before branching begins, while in the strains from Britain the germ tubes branch when quite short and are usually geniculate at one or more points. Wormald (*14*), has also recently described an ascogenous stage occurring in Britain that appears to be identical with ours, as indicated by his table showing measurements of asci and spores of both forms. In the same publication he states:

> It seems certain, therefore, that the earlier records of the *Sclerotinia* in America were not of *S. fructigena* (Pers.) Schröter, and the more recent records show that the American form is one of which the conidial fructifications are indistinguishable from those of *Monilia cinerea* Bon. Of 13 strains of *Monilia* obtained by the present writer from various sources in North America, each has proved to be a fungus with a *Monilia* stage very similar to the gray *Monilia* common in Britain, but differing from the latter in its more copious

[1] Received for publication June 21, 1924—issued Nov., 1924.

[2] Reference is made by number (italic) to "Literature cited" p. 959-960.

development of conidia when cultivated on artificially prepared culture media, while strains of *Monilia* isolated from mummied plums obtained from France and Holland have proved to be culturally similar to the form occurring in Britain. The American *Sclerotinia* would appear, therefore, to be either a distinct species or at least a form culturally distinct from the European *Monilia cinerea* Bon. * * *

Believing these differences to be sufficient to justify the consideration of the American form as a separate species, Norton and Ezekiel (*8*) have recently proposed the name *Sclerotinia americana* for the American fungus, thus raising Wormald's forma *americana* to specific rank.

In 1909 Pollock (*9*) called attention to the fact that Saccardo in volume 18 of the Sylloge Fungorum gives a description of *Sclerotinia fructicola* (Winter) Rehm, first described by Winter in 1883 under the name of *Ciboria fructicola*, from specimens on decayed peach fruits in North America, and later transferred to Sclerotinia by Rehm in a letter. He also states that as Winter's measurements of asci and ascospores correspond very closely to those given by Reade (*10*) for the ascogenous stage of the American fungus, Winter must have had this species. Pollock concludes:

> If the rule of priority is to apply to the species name first associated with the perfect stage, the correct name of this fungus is *Sclerotinia fructicola* (Winter) Rehm instead of *Sclerotinia fructigena* (Pers.) Norton.

It should be remembered that at this time the American form was commonly assigned to the last-named species.

In 1920, Pollock,[1] at the annual meeting of the Botanical Society of America submitted data to show that the species of Sclerotinia common on American stone fruits is distinct from either *S. fructigena* or *S. cinerea* of Europe. Again he called attention to Winter's description of the American form in 1883 under the name of *Ciboria fructicola* and Saccardo's transfer of the species to Sclerotinia on the authority of Rehm. Winter's (*12, p. 131*) description is as follows:

> *Ciboria fructicola* Winter nova spec. Cupulae gregariae, infundibuliformes, longissime pedicellatae, extus intusque brunnae, glabrae, usque 4 mill. diam., siccae margine involuto, extus grisae. Stipes concolor, flexuosus, usque 5 mill. longus, inferne fusco-villosus, ex epicarpio in corporem sclerotioideum fusco-atrum transformato oriens. Asci cylindracei, apice obtusi, deorsum attenuati, 8-spori, 130-160 μ longi, 8-8½ μ crassi, membrana ascorum apice incrassata et poro pertusa. Jod—. Sporae monostichae, ovoideae continuae, hyalinae, 10-12½ μ longae, 4-5½ μ latae. Paraphyses filiformes, sursum parum incrassatae hyalinae, ascos aequantes. Ad Persicae vulgaris fructus putridos. Bethlehem, Pennsylvaniae, U. S. A. leg. E. Rau.

As indicated, Winter's material was sent him from Bethlehem, by Eugene A. Rau. Recently Mr. Rau has donated his collection of fungi to the Office of Pathological Collections of the United States Department of Agriculture. Through the kindness of Dr. C. L. Shear, in charge of that office, the writers have been permitted to examine what is evidently a part of the type collection of Winter's *S. fructicola*. The packet is labeled in ink "Peziza. On decayed peach in garden, May, '83," to which is added in pencil "new species Winter." The number, 37, also appears on the packet. The contents consist of portions of dried peach fruits and sclerotia together with dried and shriveled apothecia, which appear to be identical with those of the common American brown-rot fungus. Microscopical studies of this material were made by the junior author. The method used was as follows:

A small fragment of an apothecium was selected and placed in 95 per cent alcohol for a moment. It was then transferred to distilled water for several minutes. The purpose of the treatment with alcohol was to facilitate the absorption of water. For the purpose of expanding the material to as nearly normal size as possible it was placed in a drop of 7 per cent solution of potassium hydroxide on a microscopic slide. The material was then crushed and teased apart. The solution of potassium hydroxide was then withdrawn by means of a piece

[1] Also in a letter to the senior author.

of filter paper and a drop of stain solution (eosin or safranin) was added. Material treated in this way was examined with the following results:

ASCI.—The asci are cylindrical to club-shaped with rounded apices. They taper gradually in the lower half to the point of attachment. The pore stains blue with iodine, and is brought out with great clearness by the use of this reagent. The 17 measured ranged from 117.8 to 161.5 μ in length and from 5.7 to 9.5 in width.

ASCOSPORES.—Ascospores, eight in number, hyaline, nonseptate, in upper half of the ascus. They may be arranged end to end or, as in some cases, with their long axes at an angle to the long axis of the ascus, that is, seriate, ellipsoid in shape, some with quite pointed ends but generally with rounded ends, hyaline. Of 100 spores measured, the lengths ranged from 6.8 to 13.1 μ, with the greatest number 10.2 μ. The widths varied from 3.4 to 6.8 μ with the greatest number 5.1 μ.

PARAPHYSES.—Paraphyses filiform, hyaline, septate, ranging from 119.7 to 142.5 μ long and from 1.9 to 3.8 μ wide. The tip was rounded and in some cases slightly swollen. Some were branched. Only five paraphyses were measured, due to great difficulty in determining whether or not the ones seen on the slides were of full length or broken. The ones measured were quite certainly intact and of full length. For purposes of comparison the following measurements of Sclerotinia are given. It should be noted that these measurements, regardless of the names given, are of Sclerotinias from stone fruits in America.

Investigator	Date	Name given to fungus	Host	Asci	Ascospores
Winter	1883	*Ciboria fructicola*	Peach	130 to 160 × 8 to 8.5	10 to 12.5 × 4 to 5.5.
Reade	1908	*Sclerotinia fructigena*	do	125 to 215 × 7 to 10	10 to 15 × 5 to 8.
Pollock	1909	*Sclerotinia fructigena*	Stone fruits.	130 to 179 × 9.2 to 11.5	11.4 to 14.4 × 5 to 7.
Matheny	1913	*Sclerotinia cinerea*	Peach	135 to 190 × 6.9 to 10.5	10.5 to 14.5 × 5.2 to 7.5.
Matheny	1913	*Sclerotinia cinerea*	Plum	135 to 173 × 6.8 to 10.8	8.3 to 14.2 × 5 to 7.4.
Roberts	1920	*Sclerotinia cinerea*	Peach	152 to 176 × 8 to 10	6 to 15 × 4 to 8.
Dunegan	1922–1923	*Sclerotinia cinerea*	do	130 to 186 × 5.7 to 13.3	9.5 to 14 × 5.7 to 7.6.
Dunegan	1924	*Sclerotinia fructicola* (Winter's type material.)	do	117 to 161 × 5.7 to 9.5	6.8 to 13.1 × 3.4 to 6.8.

The table shows a series of measurements, exclusive of Rau's material, in which the range for asci is from 125 to 215 μ in length and from 5.7 to 13.3 μ in width. For ascospores the range is from 8.6 to 15 μ in length and from 4 to 8 μ in width. These measurements agree fairly well with those of the type material of *S. fructicola*. That there should be some variations is to be expected when one considers the differences in the technique employed and also from the fact that Winter himself used dried material (Rau collected it in May, and Winter published his description in the September number of Hedwigia of the same year, namely, 1883), and that the measurements made by the present junior author were of material that had been dry for a little short of 41 years. It therefore seems certain that in 1883 Rau collected and Winter described the species of Sclerotinia which Norton in 1902 showed to be the ascogenous stage of our common brown-rot fungus.

Since, as previously noted, it has been well established that the name *S. fructigena* belongs to a European species that is distinct from the American, only the following binominals need be considered: *Sclerotinia cinerea* (Bon.) Schröter, *Sclerotinia fructicola* (Wint.) Rehm, and *Sclerotinia americana* (Wormald) Norton and Ezekiel.

Of these names *Sclerotinia cinerea* would be the correct one to apply to the American form, could it be shown to be identical with *S. cinerea* of Europe, if one believes it to be proper to choose the first-known name given to any form of the fungus, be it the ascogenous stage or a conidia-bearing stage, and properly published with an adequate description. If one believes that the first name applied to the ascogenous form and accompanied by an adequate description should be the one chosen, then *S. fructicola* would be the correct name both for the American form and the European form, again assuming their specific identity. If the American fungus is considered specifically distinct from the European, then the correct name is *Sclerotinia fructicola*, since, so far as known, it is the name first given to any stage of the fungus, the description is adequate, and it is also a name that should be acceptable to those who believe that the first name given the perfect stage should be chosen.

The name *Sclerotinia americana* is untenable whether or not one considers the American form specifically indentical with the European. In the former case *S. cinerea* holds priority, while in the latter case *S. americana* is far antedated by *S. fructicola*.

Though at first the writers were inclined to believe there was sufficient evidence to justify consideration of the American form as specifically distinct from the European, further study has indicated that the differences, mainly physiological, are not sufficient to be regarded as specific. It seems best to regard the American fungus as a form or rather as consisting of a number of forms or races of *Sclerotinia cinerea*, accepting as the correct specific name the one first applied to the conidial stage of the European fungus.

Races or strains of the European form have been recognized and studied by Wormald (*13*), Killian (*5*), and others; of the American form by Wormald (*14*) and by Ezekiel (*4*). The writers have grown strains of the American fungus in parallel cultures with the European *S. cinerea* and have found the same differences noted by Wormald.

None of the American strains had quite the characteristically scalloped margins which the European form has when grown in plate cultures, but some of them had scalloped margins not greatly different from those of the European form (Pl. 1, *A* and *B*). The conidia of the American strains produced germ tubes which did not branch until they had become considerably longer than those produced by conidia of the European form, the germ tubes of which showed much branching shortly after their emergence. On the other hand, the strains of American origin when grown on an extract of dried peaches and subjected to the oxidase test, in accordance with a method described by Wormald (*13*), gave results which are in all respects identical with those produced by *S. cinerea* from Europe. The strains of the American form show great differences in their growth on artificial culture media. Although most strains when grown on 4 per cent potato agar produce an abundance of conidia, some strains produce conidia in abundance only for a short time. With these strains the production of conidia becomes less with each transfer, and finally only microconidia are formed. One strain obtained from a single ascospore has been grown by the senior writer for four years and now produces conidia even more profusely than at first. Moreover, it produces conidia on many media on which every other strain tried has produced none. The differences in growth on artificial culture media between a strain such as this and one which produces only microconidia are very striking (Pl. 2, *A* and *B*). The former forms a thin web over the surface of the medium, most of which is covered with numerous grayish masses of conidia. The latter slowly develops a thick white mat, having a powdered appearance caused by the profuse production of microconidia. The growth seldom covers more than a small portion of the plate or tube slant, possibly because

development is so slow that the medium becomes too dry for further growth. If differences in reaction to artificial culture media alone are to be considered of specific significance, then the American fungus should be regarded as made up of several species. If, in addition to these cultural differences, the slight morphological differences exhibited by germinating conidia be considered, the separation of the European and American forms into two species is much more defensible. From a practical point of view this is very objectionable, however, because it would make impossible the specific identification of any except living material. It may be that further investigations, particularly of the ascogenous stages, will reveal important morphological differences, but until such differences are noted, it would seem much more logical and much more practicable to consider the American form and the European form as a single species having the name *Sclerotinia cinerea* (Bon.) Schröt.

SUMMARY

The common "brown-rot" fungus of America has been given at various times the following names: *Oidium fructigenum*, *Monilia fructigena*, *Sclerotinia fructigena*, *Sclerotinia fructicola*, *Sclerotinia cinerea*, *Sclerotinia cinerea* forma *americana*, *Sclerotinia americana*. By examination of type specimens it is shown that *Sclerotinia fructicola* (Winter) Rehm, described by Winter in 1883 under the name of *Ciboria fructicola*, is identical with the ascogenous stage of the American brown-rot fungus, thus sustaining the contentions of Pollock. If it is assumed that the American fungus is different from the European form commonly known as *Sclerotinia cinerea* (Bon) Schröter, then its name should be *Sclerotinia fructicola* (Winter) Rehm, the first name known to be applied to any stage of it and also the first name applied to the ascogenous stage. If the American form and the European are considered identical, then the name should be either *Sclerotinia cinerea*, if one believes the first known name properly applied to any stage should be adopted as correct, or *S. fructicola*, if it is believed that the first known name properly applied to the ascogenous stage should be considered the correct one. The known differences between the two forms are chiefly physiological as revealed by differences in growth on artificial media. It is shown that the American strains may show differences in their reaction to culture media at least as great as those between strains from America and Europe respectively. It is believed that at the present time the known differences between the American and European forms are not sufficiently great to warrant considering the two forms as separate species. The name *Sclerotinia cinerea* (Bon) Schröt. is preferred by the authors.

LITERATURE CITED

(1) Aderhold, R., and Ruhland, W.
1905. zur kenntnis der obstbaum-sklerotinien. Arb. K. Biol. Anst. f. Land- u. Forstw. 4: 427–442, illus.

(2) Bonorden, H. F.
1851. handbuch der allgemeinen mykologie. 336 p., illus. Stuttgart.

(3) Conel, J. L.
1914. a study of the brown-rot fungus in the vicinity of champaign and urbana, illinois. Phytopathology 4: 93–101.

(4) Ezekiel, W. N.
1924. strains of the brown-rot fungus, sclerotinia americana. (Abstract) Phytopathology 14: 32.

(5) Killian, K.
1921. über die ursachen der spezialisierung bei den askomyzeten. i. die monilia cinerea der kirschen. Centbl. Bakt. (II) 53: 560–597, illus.

(6) MATHENY, W. A.
1913. A COMPARISON OF THE AMERICAN BROWN-ROT FUNGUS WITH SCLEROTINIA FRUCTIGENA AND S. CINEREA OF EUROPE. Bot. Gaz. 56: 418–432, illus.
(7) NORTON, J. B. S.
1902. SCLEROTINIA FRUCTIGENA. Trans. Acad. Sci. St. Louis 12: 91–97, illus.
(8) ——— and EZEKIEL, W. N.
1924. THE NAME OF THE AMERICAN BROWN-ROT SCLEROTINIA. Phytopathology 14: 31–32.
(9) POLLOCK, J. B.
1909. NOTES ON PLANT PATHOLOGY. Rpt. Mich. Acad. Sci. 11: 48–54.
(10) READE, J. M.
1908. PRELIMINARY NOTES ON SOME SPECIES OF SCLEROTINIA. Ann. Mycol. 6: 109–115.
(11) SCHRÖTER, C. J.
1893. PILZE. (COHN, F. KRYPTOGAMEN-FLORA VON SCHLESIEN, Bd. 3, Hälfte 2. Breslau.)
(12) WINTER, G.
1883. UEBER EINIGE NORDAMERIKANISCHE PILZE. Hedwigia 22: 67–72, 129–131.
(13) WORMALD, H.
1919–20. THE "BROWN-ROT" DISEASES OF FRUIT TREES, WITH SPECIAL REFERENCE TO TWO BIOLOGIC FORMS OF MONILIA CINEREA BON. I–II. Ann. Bot. 33: 361–404, illus., 1919; 34: 143–171, illus., 1920.
(14) ———.
1921. ON THE OCCURRENCE IN BRITAIN OF THE ASCIGEROUS STAGE OF A "BROWN-ROT" FUNGUS. Ann. Bot. 35: 125–135, illus.
(15) WORONIN, M.
1900. ÜBER SCLEROTINIA CINEREA AND SCLEROTINIA FRUCTIGENA. 38 p., illus. St. Pétersbourg. (Mém. Acad. Imp. Sci. St. Pétersbourg, VIII Cl. Phys.-Math. v. 10, no. 5.)

PLATE 1

Six-day-old cultures of *Sclerotinia cinerea* on 4 per cent potato agar plates.

A.—A culture of the fungus isolated from a mummied plum. England, 1920. Note the characteristically scalloped margins.

B.—A culture of the fungus isolated from a decayed peach fruit. Georgia, 1923. Note the scalloped margins resembling somewhat those of the European form, Plate 1, A.

A
B

PLATE 2

Six-day-old cultures of *Sclerotinia cinerea* on 4 per cent potato agar plates.

A.—A culture of the fungus from a decayed peach. Georgia, 1923. Microconidia are produced in profusion. Note how little resemblance there is between this culture and those shown in Plate 1, A and B, and Plate 2, B.

B.—A culture of the fungus from a mummied plum. Virginia, 1921. The production of conidia is quite profuse.

PRELIMINARY RESULTS WITH THE BORAX TREATMENT OF CITRUS FRUITS FOR THE PREVENTION OF BLUE MOLD ROT[1]

By HARRY R. FULTON, *Pathologist, and* JOHN J. BOWMAN, *Junior Pathologist, Office of Fruit Disease Investigations, Bureau of Plant Industry, United States Department of Agriculture*

Recent studies by the senior author on the effect of ultraviolet light in disinfecting the surface of citrus fruits, details of which will be published in the near future, have indicated that more than 99 per cent of blue-mold spores may be killed very quickly by light of short wave lengths, and at comparatively low cost, but that blue-mold rot is not proportionately checked. The two weak points in the ultraviolet treatment seem to be (1) the difficulty in killing the last small percentage of Penicillium spores, and (2) the lack of any later protection against stray spores that remain unkilled or may reach the fruit. Being thus strongly impressed with the desirability of using some agent that would have a continuing effect, the writers have undertaken the testing of a large number of mild chemical reagents with a view to finding inhibiting rather than killing substances. The stronger disinfectants would be objectionable, because their poisonous character would not permit residues to be left and because many of them would actually injure the surface of the fruit if not immediately washed off.

The general procedure has been to select chemicals for preliminary tests largely on the basis of cheapness and availability. Spores of Penicillium were treated with relatively strong solutions of these chemicals for periods of 1 to 24 hours, and were then plated to determine the killing effect. Parallel tests were made for inhibition. Any reagent that seemed at all promising was then applied to a few citrus fruits to determine whether it would injure the skin. If it seemed safe to use, an actual test was made to determine its protective action on severely wounded and inoculated fruit held under conditions of temperature and moisture favorable for blue-mold development. Usually some one of the stronger fungicides was included in each test as a basis for comparison.

Holding tests have been made thus far with fruit treated with solutions of the following chemicals: Sodium sulphate, sodium bisulphite, sodium borate, sodium fluoride, sodium perborate, sodium chloride, potassium permanganate, potassium borate, copper borate, bichloride of mercury, boric acid, salicylic acid, benzoic acid. Among these sodium borate, or borax, has seemed to give best protection against blue-mold rot.

The results of one holding test, made March 14, 1924, which included borax along with certain other materials will serve as an illustration and is shown in Figure 1. California navel oranges purchased in the Washington, D. C., market were used. The fruit was soaked for 10 minutes in inoculum carrying about 500,000 per cc. of mixed *Penicillium digitatum* and *P. italicum* spores. The fruits were dried, then atomized with the chemical solution (the control with water); dried again; punctured 100 times with pins to a depth of about half way through the peel. They were wrapped in waxed paper, packed in a tight

[1] Received for publication July 3, 1924—Issued Nov. 1, 1924. This paper has been referred to the Bureau of Chemistry, United States Department of Agriculture, for consideration regarding the use of borax.

barrel with wet newspaper between each two layers of fruit; and were kept at room temperature of about 72° F. Examination for rot was made every three days. The results show some benefit from all of the chemicals; 1:5000 bichloride of mercury, 5 per cent boric acid, and 5 per cent sodium bisulphite had approximately the same effect; and 5 per cent sodium borate (borax) was distinctly

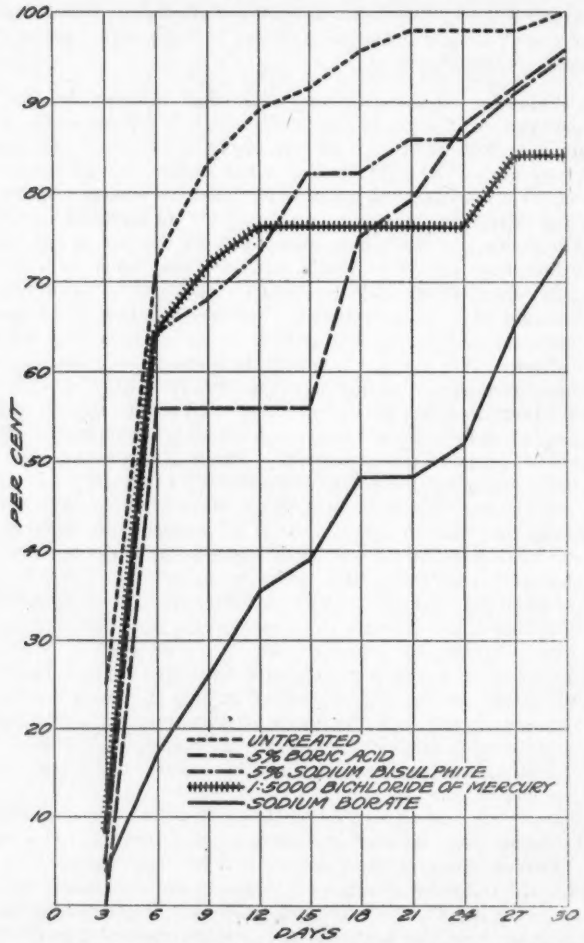

FIG. 1.—Percentages of blue-mold rot developing in oranges treated with various chemicals and those untreated during 30 days

more effective, particularly during the first 24 days of the test. In Figure 2 are shown the average results of 15 tests on oranges of 5 per cent borax treatment, as compared with no treatment, and 5 tests on lemons. These tests were made at various times. In all cases the fruit was punctured at 100 points, was inoculated with a suspension of blue-mold spores, and was packed between wet paper. The strength of the inoculum was varied in some of the tests, as was the sequence

of puncturing, inoculating, and treating with borax. The method of applying the 5 per cent borax solution was either by dipping the fruit momentarily in the solution, or by soaking for 1 minute or for 10 minutes, or by atomizing over the fruit, or by applying with a brush; all of these methods proved effective. The averages are based on 491 treated and an equal number of untreated fruit for

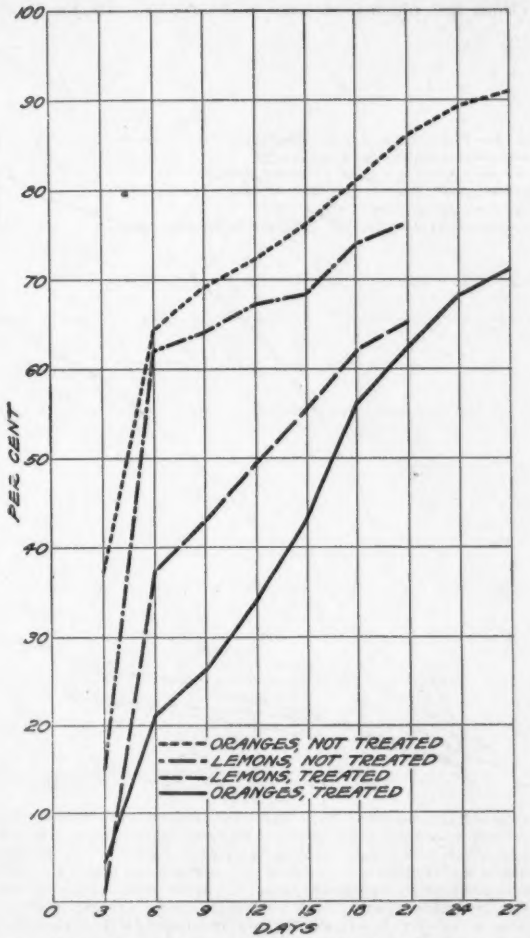

FIG. 2.—Percentages of blue-mold rot developing in oranges and in lemons treated with 5 per cent borax solution and untreated during 27 and 21 days

the oranges, and on 270 fruits for the lemons. They show the effectiveness of the treatment under conditions of infection far more severe than would occur in even the worst commercial practice. The treatment with 5 per cent borax solution resulted under these exceedingly severe conditions in a distinct reduction in blue-mold rot, but did not give what would be considered satisfactory control. The treatment seemed to be more effective on oranges than on lemons.

In certain other tests the fruit was not only punctured, but was severely bruised by dropping several times from a table to the floor, and several slices resembling very severe clipper cuts were cut from the outside of the peel. In such cases soaking one minute in 5 per cent borax solution had a very satisfactory protective effect, but the mere brushing on of the solution was less effective.

A preliminary test to determine the value of the borax treatment under commercial conditions was made in Florida with oranges. In one series of tests

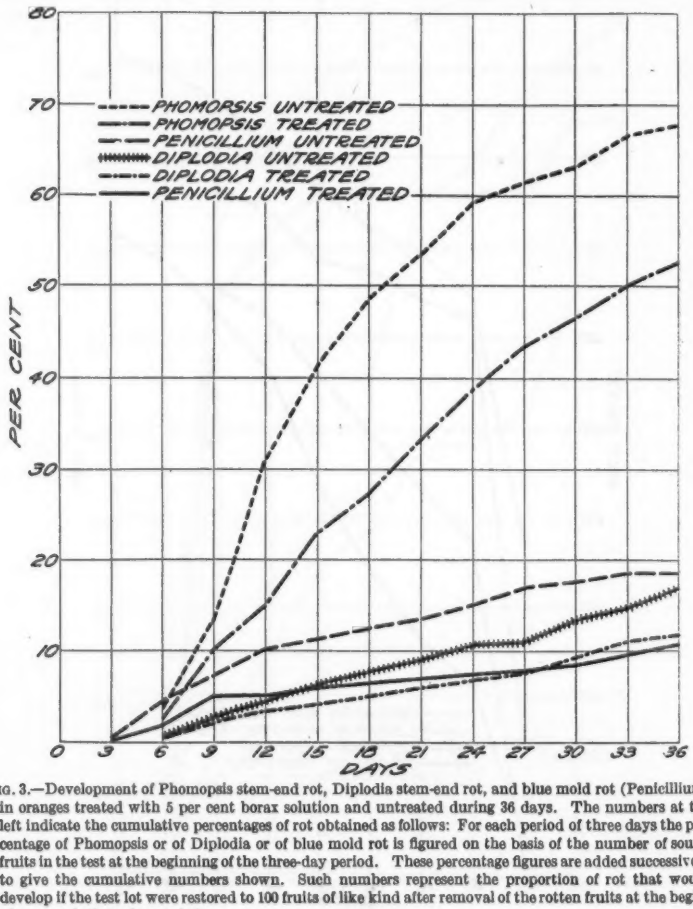

FIG. 3.—Development of Phomopsis stem-end rot, Diplodia stem-end rot, and blue mold rot (Penicillium) in oranges treated with 5 per cent borax solution and untreated during 36 days. The numbers at the left indicate the cumulative percentages of rot obtained as follows: For each period of three days the percentage of Phomopsis or of Diplodia or of blue mold rot is figured on the basis of the number of sound fruits in the test at the beginning of the three-day period. These percentage figures are added successively to give the cumulative numbers shown. Such numbers represent the proportion of rot that would develop if the test lot were restored to 100 fruits of like kind after removal of the rotten fruits at the beginning of each three-day period

samples of 100 fruit were taken from the packing houses; each sample was divided into two lots, one lot was dipped momentarily through 5 per cent borax solution and the control lot through water; the fruit was allowed to dry, and was held for several weeks at approximately 74° F. in a rather moist atmosphere. These conditions of temperature and moisture are more favorable for rot than usual commercial conditions, but were considered desirable in order to induce enough rot for a definite showing. In Figure 3 the averages are given for 11 sample lots of 50 oranges each, representative of Florida oranges in late April,

including Valencias in their prime and seedling oranges that were dead ripe. There is a distinct reduction in all three rots, Phomopsis and Diplodia stem-end rots showing decided reduction as well as blue-mold rot. This reduction in stem-end rots was an entirely unexpected outcome of the experiment. One possibility is that the borax solution may penetrate and disinfect the calyx edges or other portions of the button in which these two stem-end rot fungi are established, and from which they later extend their growth into the stored fruit.

Two commercial shipments of boxes of oranges and of grapefruit were made, one during April and one in May, 1924, from points in Florida in regular fruit cars under refrigeration to Seattle, Wash., and by ordinary express to Washingon, D. C. Not enough blue-mold rot developed in either the treated or the untreated fruit for definite showing, even during a holding period of several weeks duration after arrival. The boraxed fruit in these shipments again showed a distinct reduction of stem-end rot when compared with the controls. Further tests will be made to determine the effect on blue-mold rot of the borax treatment in commercial shipments.

The question arose as to whether increasing the strength of the borax solution would give better control. At ordinary air temperature water saturation occurs at about 6 per cent or 7 per cent of borax, but solubility increases rapidly with rise in temperature. At 85° F. it is approximately 7 per cent; at 113°, approximately 14 per cent; and at 122°, approximately 18.5 per cent. In California lemons and oranges are usually washed for several minutes in water between 115° and 120° for control of brown rot without bad effect. In the warm-water tests the writers have used 10 per cent commercial borax in water maintained at 122°, on plump but not turgid fruit that had been off the trees at least 10 days when purchased from the market. Seven tests, two with oranges and five with lemons, are averaged in figure 4. The percentages of rot are based on

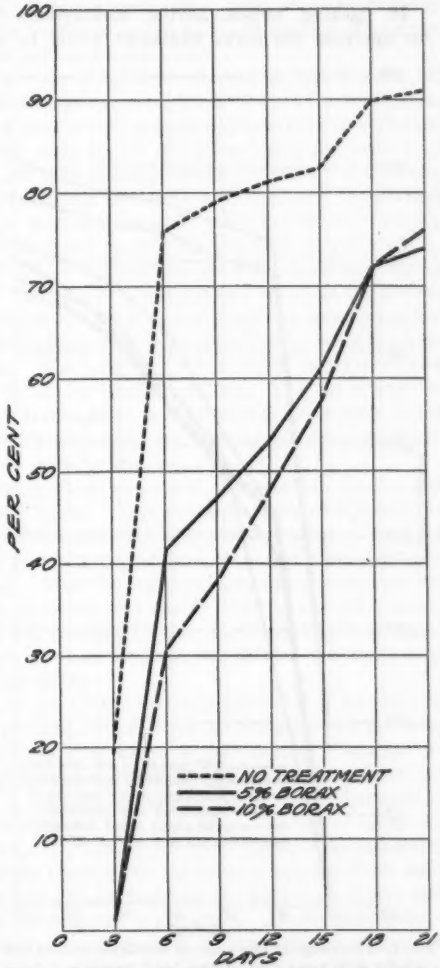

FIG. 4.—Percentages of blue-mold rot developing in citrus fruit treated with 5 per cent and with 10 per cent borax solution and untreated during 21 days

275 fruit originally given each treatment. There is some difference in favor of the 10 per cent as compared with the 5 per cent borax dipping treatment. It is possible that soaking tests of several minutes in the warm solution would show an increased effectiveness. The question requires further testing under commercial conditions of handling the fruit.

In packing houses having soaking-tank equipment a convenient place for applying the borax treatment would be in this tank. Usually the fruit passes from the soaking tank to scrubbing brushes over which streams of water play. These would wash off most or all of the borax. In the absence of a soaking tank, or for the purpose of leaving as much as possible to dry on the fruit surface, the borax solution might be played over the scrubbing brushes in small streams from perforated pipes leading from overhead tanks, or some atomizing device might be used just before the fruit enters the drier. Where polishing brushes are used after the fruit has dried, much of the borax coating would be removed. Tests were made to determine whether the removal of the borax coating, either by washing the freshly treated fruit or by brushing those on which the borax had dried, would materially lessen the protective effect. The fruit was heavily inoculated and was packed away between layers of moist paper at room temperature. Figure 5 shows the average results of seven separate tests, five with lemons, and two with oranges, totaling 340 fruits. The strength of the borax solution was 5 per cent for five of the tests and 10 per cent for two.

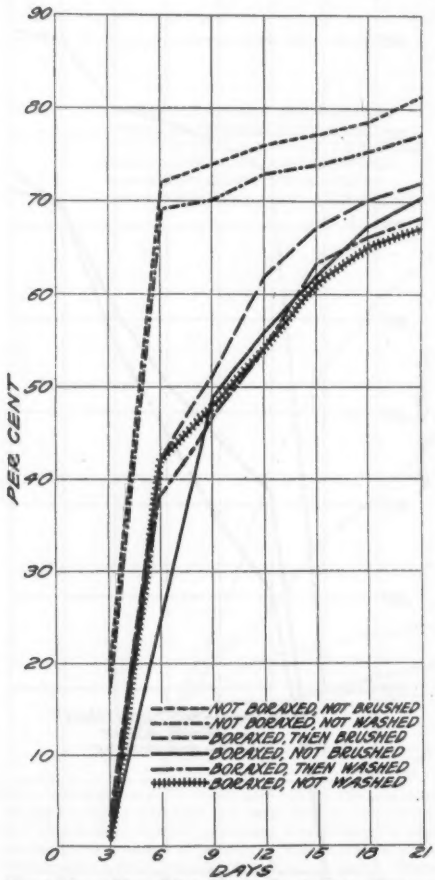

FIG. 5.—Percentages of blue-mold rot developing in citrus fruit treated with borax solution (two tests), treated with borax solution and later washed, treated with borax solution and later brushed, and untreated (two tests) during 21 days

These results indicate that removal of the coating of borax really makes little difference. This is at variance with the working hypothesis on the basis of which this work was undertaken. It may be that borax penetrates to some extent the tissues, especially at wounds, and thus has a residual effect even though the surface crystals are not present in quantity. However, one would naturally suppose that a surface coating of small crystals of an antiseptic substance that would readily dissolve in any moisture that would allow spore germination would give

added effectiveness in preventing such germination or subsequent invasion by the fungus mycelium. After the brushing the deposit of borax crystals remained, or was even increased in depressions, but was removed from the high places.

Practical packing-house tests will be required to determine the most effective and economical way of applying the borax treatment. From these preliminary laboratory tests it seems that the treatment would be about equally effective in any one of the several methods of application discussed.

Tests were made on the effectiveness of borax treatments at various intervals after artificial inoculation. The best results were obtained when the treatments followed immediately. With the lapse of two and one-half hours the treated fruit was no better than the untreated control. On the other hand, the tests with "commercially sound" fruit taken from packing houses, frequently one or two days after picking, indicate a material reduction in blue-mold rot and in stem-end rot, as is shown in figure 3. It is important to avoid delay in treating the fruit, and the borax treatment must not be relied upon to make up for careless handling. All the tests with severely wounded fruit indicate that the borax treatment will by no means prevent all of the rot. In general the laboratory tests had the advantage over carelessly handled commercial fruit of receiving the treatment promptly after wounding and had the disadvantage of being subjected to exceedingly severe wounding and holding conditions. The borax treatment should be regarded as a supplement to and not as a substitute for careful handling. It gives promise of having a place in protecting the fruit against a considerable proportion of the blue-mold rot that is likely to occur even with very careful handling, especially that incident during and after the packing process.

Borax has the advantage of being cheap and readily obtainable. It does not actively corrode metal and is not a poison. It is an article of common household use. The coating, even when freshly made with 10 per cent solution, is not very conspicuous on oranges and lemons; on grapefruit it shows at first somewhat more prominently as a grayish coating. After the fruit has been wrapped and packed and held for a week or more, one must look very closely to detect any difference in appearance between the treated and untreated fruit. It does not seem probable that the borax coating, even if all is left on the fruit, will detract materially from its appearance or affect its marketability.

As is well known, regulations of the United States Department of Agriculture, made under the pure foods act, prohibit the use of borax or certain other preservatives in food products and restrict their use on the surface of such products. In the case of citrus fruits the application of borax is made to the outside of the peel, a portion of the fruit that is not regarded as edible and that is discarded in the ordinary consumption of the fruit. If the fruit is washed before using, the adhering borax is readily removed. In commercial establishments for extracting juice and for manufacture of citrus by-products the general practice is to wash the fruit before using. In the making of citrus drinks the fruit is doubtless used sometimes without washing and the peel put in the drink. In this case there is considerable dilution with liquid. Our tests show that an orange of medium size, on an average, will remove 1 cc. of 5 per cent borax solution when dipped. Perhaps half of this drains off. On this basis a single orange might carry 0.025 gram (0.4 grain) dried borax on its surface. The therapeutic dose is given as 0.750 gram (12 grains), and is the equivalent of what might be carried on about 30 oranges.

Chemical analyses are being made by the Office of Soil Fertility Investigations of this bureau to determine the amount of borax present on and in the peel and in the edible pulp portion of oranges and of lemons that had been held 15 days

after treatment with borax solution of 5 per cent and of 10 per cent strength. Preliminary results indicate that the amounts present are even much smaller than those indicated and that the borax does not penetrate to the edible portion of the fruit.

No injury to the fruit through the use of borax solution has been observed. Most of the tests were made with fruit obtained on the market some time after picking, but a number of tests on grapefruit and on oranges were made with freshly picked fruit. The effect on very turgid fruit has not been fully tested.

SUMMARY

Preliminary tests have shown that commercial borax (sodium borate) solution in strength of 5 per cent or 10 per cent applied to the surface of oranges or lemons and allowed to dry greatly reduces blue-mold rot under experimental conditions that are unusually favorable for rot development.

Oranges and grapefruit handled in a commercial way, when treated with the borax solution, showed a marked reduction of both Phomopsis and Diplodia types of stem-end rot, as well as of blue-mold rot.

The borax treatment gives promise of being commercially valuable, in conjunction with careful handling of the fruit, in reducing losses from blue-mold rot.

SNAILS AS PREDISPOSING AGENTS OF SUGAR CANE "ROOT DISEASE" IN LOUISIANA[1]

By R. D. RANDS

Pathologist, Office of Sugar-Plant Investigations, Bureau of Plant Industry, United States Department of Agriculture[2]

Root disease, or rootrot, has been considered a major factor in the gradually declining yields of sugar cane in Louisiana. The losses, particularly in "stubble," or ratoon crops, have lately attained such proportions as to render of questionable value the practice of growing even one year stubble. Although root troubles have in the past received but little scientific attention in Louisiana, rootrot in other countries has usually been ascribed to various fungi.

Close study of a large number of incipient cases in the principal sugar sections of Louisiana has revealed that a small snail (*Zonitoides arboreus*, Say)[3] may be primarily responsible for the trouble. So far as known to the writer, snail injury has not hitherto been reported anywhere on sugar cane. The damage, which is most extensive on the soft, white, terminal portion of the root, consists typically of minute cavities or pits 0.3–2.0 mm. deep and of similar diameter, resulting frequently in direct death of the growing point, and the development of secondary rootlets farther back. The latter, in turn, may be attacked, giving the roots a fibrous, bunchy appearance. On the older portions of the root the pits extend only to the hard central bundle sheath. No injury to the rhizome, or underground stalk, has been observed. Around the pits and abrasions lesions commonly develop, due to invasion of the weakened tissues by soil inhabiting microorganisms. The extension of these combined with further snail injury gradually brings about the final death of the root. In advanced cases most of the older, deeper roots have died forcing successive development of new ones nearer the surface of the soil. While root lesions apparently not connected with snail damage have been observed, most of the root deterioration seems to be directly proportional to the extent of such injury.

That the above-mentioned species of snail is responsible for the root pitting has been repeatedly confirmed both by direct field observations and by feeding tests with isolated snails in the laboratory. As many as 150 individual snails have been counted in casual examination of the soil about the roots of a single backward plant in a poorly drained field. They commonly occur in the earthworm

[1] Received for publication July 28, 1924—issued Nov., 1924.

[2] Grateful acknowledgments are made to Messrs. D. W. Pipes, C. C. Krumbhaar, and Elliott Jones, managers of Southdown Plantation, Houma, La., for furnishing laboratory facilities and asistance in this investigation.

[3] The writer is indebted to Dr. Paul Bartsch, Curator of Mollusks, U. S. National Museum, Washington, D. C., for giving the following information:

"This mollusk is known as *Zonitoides arboreus* (Say). It has been reported from all the States of our Union, also from Canada as far north as Great Slave Lake. We have likewise had it reported from certain of the West Indian Islands. Normally, it makes its home under the dead bark of fallen trees and old rubbish heaps, squeezing into small crevices.

"Sugar cane, as I recall it, has quite a lot of small roots about its base, and drooping dead leaves hanging about the stalks, a condition not unlike a rubbish pile. It is, therefore, not surprising that we should find the organism in question in such locations. It may fall from these roots onto the soil or get down farther in the burrows of other animals."

tunnels and in the myriad other passages through the soil. Severely affected plants, when not killed outright in the early stages of growth, remain backward on account of their small and impoverished root systems, fail to tiller properly, and give at best an abnormally thin stand with consequently great reduction in yield. In certain of the older sections of the Louisiana Sugar Belt this year it is practically impossible to find a plant of the commonly grown varieties which does not show more or less of this root injury. However, in newly cleared land never before planted with cane, it is rare. Slight injury has also been observed on sorgo[4] and on maize, the latter being the only crop with interplanted cowpeas, commonly used in rotation with sugar cane.

Severe root injury and the same species of snail were also found on cane growing in the so-called "saw grass" or peaty soils of southern Florida. In the light sandy soils of the cane sirup sections of northern Florida and Georgia but slight injury was generally observed.

While the relative importance of primary and secondary agents in bringing about the final complex condition known as "root disease" in Louisiana is yet to be determined, severe root injury by snails is apparently a major predisposing and contributing factor.

[4] This is more generally known as sweet sorghum.

GREENHOUSE EXPERIMENTS WITH ATMOSPHERIC NITROGEN FERTILIZERS AND RELATED COMPOUNDS[1]

By F. E. ALLISON, *Biochemist*, and E. B. VLIET, *Assistant Chemist, Fixed Nitrogen Research Laboratory*, J. J. SKINNER, *Biochemist*, and F. R. REID, *Assistant Biochemist, Soil-Fertility Investigations, Bureau of Plant Industry, United States Department of Agriculture*

INTRODUCTION

In connection with a study at the Fixed Nitrogen Research Laboratory on the possible transformation products of cyanamid,[2] there was obtained a number of materials and mixtures concerning which there is either very little known, or concerning which there is still some doubt as to their fertilizing value. Thus, in the preparation of urephos, a product was obtained in which approximately 55 per cent of the nitrogen was present as urea, 30 to 35 per cent as guanylurea, 5 per cent as ammonia, and the balance in undetermined forms, a small part of which was dicyanodiamide. There is very little data available on the use of guanylurea as a fertilizer, and the literature on cyanamide and especially on dicyanodiamide contains many conflicting statements. The experiments reported here deal with these nitrogenous materials, as well as others, such as sodium nitrate and calcium nitrate, included for comparison. In addition, a few experiments were included in which calcium sulphate, potassium sulphate, and acid phosphate, but no nitrogen compounds, were added. A portion (Table I) of the experimental work was conducted in 1919, but a later group (Table II) of pot tests was conducted during the early part of 1922.

SOILS, PLANTS, AND FERTILIZERS USED IN THE EXPERIMENTS

The two types of soil used were the Norfolk sandy loam, a Coastal Plain soil obtained from near Norfolk, Va., and the Chester loam, a Piedmont Plateau soil secured near McLean, Va. Both soils are rather poor and typical of a large area along the Atlantic coast.

Wheat, beans, and cowpeas were grown. There was some hesitancy about using legumes in an availability experiment with nitrogen materials, but since legumes are widely different from wheat, it was decided to include them. The results with wheat and beans were satisfactory from the viewpoint of the experiment, but the cowpea developed so many nodules that it grew luxuriantly regardless of the nitrogen added. These results were therefore discarded. With the exception of potassium sulphate and calcium sulphate, which are chemically pure substances, the materials [3] used, together with their composition, are as follows:

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[1] Received for publication June 5, 1924—issued Nov., 1924 These experiments were conducted at the Arlington Experiment Farm, Rosslyn, Va., the Soil-Fertility greenhouses being used.

[2] Crude calcium cyanamid, not hydrated or oiled.

[3] The preparation of some of these materials is given in an earlier publication. See ALLISON, F. E., BRAHAM, J. M., and MCMURTREY, J. E. FIELD EXPERIMENTS WITH ATMOSPHERIC-NITROGEN FERTILIZERS. U. S. Dept. Agr. Bul. 1180, 44 p., illus. 1924.

Fertilizer	Composition (per cent)	
	N	P_2O_5
Ammonium sulphate	21.02	
Sodium nitrate	16.16	
Calcium nitrate	12.55	
Urea	45.70	
Ammonium nitrate	33.93	
Ammoniated superphosphate	5.38	[a] 14.66
Cyanamid (unhydrated and unoiled)	20.27	
Urephos	6.30	[b] 3.66
Guanylurea sulphate	33.23	
Dicyanodiamide	66.43	
Acid phosphate		[c] 16.12
Calcined phosphate		[d] 17.53

[a] Solubility in 2 per cent citric acid; total, P_2O_5—17.45 per cent.
[b] Solubility in 2 per cent citric acid; total, P_2O_5—6.36 per cent.
[c] Solubility in ammonium citrate; total, P_2O_5—17.50 per cent.
[d] Solubility in 2 per cent citric acid; total, P_2O_5—27.16 per cent.

SOIL PREPARATION AND FERTILIZATION

The sieved moist soils were weighed out into portions equivalent to 10 pounds of air-dried soil and the fertilizers thoroughly mixed with each portion. Two pots were used in each treatment. When the young plants were about a week old, they were thinned to 5 and 3 plants per pot, respectively, for the wheat and beans in the first experiment, and 10 plants per pot for the wheat in the second experiment. The general plan of the experiment is apparent from Tables I and II.

The quantities of fertilizers used were based on field applications, assuming 2,000,000 pounds of soil per acre to a depth of 6 inches. All pots, except those designated as "no fertilizer," received 80 pounds of P_2O_5 and 40 pounds of K_2O per acre in the forms of acid phosphate and potassium sulphate, respectively, except where otherwise noted. Ammonia was added at the rates of 10, 40, 80, and 160 pounds per acre. Where acid phosphate was used with cyanamid, the materials were applied separately. In some instances, calcined phosphate was used in admixture with cyanamid and also in one ammonium sulphate series for comparison. In the cases of urephos and ammoniated superphosphate (in the lowest application) acid phosphate was used to bring the P_2O_5 content up to the proper amount. With the medium and heavy applications of ammoniated superphosphate, however, the P_2O_5 contained in the material itself was in excess of the application decided upon. The nitrogenous materials were applied at various rates depending upon the material used. Adequate control pots were included in which applications of phosphate and potash were made, but no nitrogen.

EXPERIMENTAL RESULTS

AVAILABILITY STUDIES WITH BEANS AND WHEAT

The bean and wheat plants were harvested at the end of five and eight weeks, respectively. The relative green weights of the plants grown on the two soils with the different sources of nitrogen are summarized in Table I.

An examination of the table shows that ammonium sulphate, ammonium nitrate, ammoniated superphosphate, cyanamid, and urea all gave good increases in yields over the no-nitrogen fertilizer pots. The relative values of the different nitrogen carriers varied at the different rates of application and also varied with the soil and crop grown, as might be expected. The variations between the results obtained with the fertilizers used under a given set of conditions were,

however, not large but usually within experimental error. The comparatively limited data would not justify close distinctions between the values of the different forms of nitrogen. It is especially significant that cyanamid, which is ordinarily considered very slowly available and of questionable value when used in large applications in the field, proved to be very readily available under greenhouse conditions when thoroughly mixed with the soil. (See Pl. 1, A.)

The green weights secured with urephos were fairly good, but on the average poorer than with the sources of nitrogen discussed above. This was very likely due to the high content of guanylurea. Where the latter compound was used alone, it showed a marked retarding or toxic effect at the higher application, especially with beans, but there were no burning effects or dropping of the leaves noticeable. (See Pl. 1, B.) Where a mixture of urea and guanylurea nitrogen were in the approximate proportions found in urephos, the yields were the same within experimental error.

TABLE I.—*Summary showing green weights of beans and wheat grown with various sources of nitrogen, expressed on a percentage basis*

Source of nitrogen	Norfolk sandy loam		Chester loam	
	Beans	Wheat	Beans	Wheat
FERTILIZER RATIO [a]—1-8-4				
No nitrogen	100	100	100	100
Ammonium sulphate	110	127	118	122
Do.[b]	119	113	130	118
Ammonium nitrate		115		138
Ammoniated superphosphate	141	91	112	126
Cyanamid [b]	122	119	139	125
Urea	107	116	123	121
Guanylurea sulphate	99	103	101	101
Urea 70 per cent, guanylurea sulphate 30 per cent	125	121	104	128
Urephos	104	111	102	125
Dicyanodiamide	92	86	121	99
FERTILIZER RATIO—4-8-4				
No nitrogen	100	100	100	100
Ammonium sulphate	137	153	135	183
Do.[b]	174	142	158	186
Ammonium nitrate	144	133		206
Ammoniated superphosphate [b]	153	127	154	169
Cyanamid [b]	139	179	127	158
Urea	187	135	138	162
Guanylurea sulphate	91	98	110	131
Urea 70 per cent, guanylurea sulphate 30 per cent	128	148	139	172
Urephos		143		171
Dicyanodiamide	76	70	120	100
FERTILIZER RATIO—16-8-4				
No nitrogen	100	100	100	100
Ammonium sulphate	231	246	298	353
Do.[b]	238	217	300	352
Ammonium nitrate	280	167	266	342
Ammoniated superphosphate [c]	264	157	304	428
Cyanamid [b]	260	270	278	349
Urea	255	262	252	329
Guanylurea sulphate	77	108	71	175
Urea 70 per cent, guanylurea sulphate, 30 per cent	215	192	223	325
Urephos		187	182	311
Dicyanodiamide	42	44	80	96

[a] The term fertilizer ratio refers to the percentage of NH_3, P_2O_5, and K_2O, in the order named, as is customary in fertilizer practice.

[b] These pots received calcined phosphate.

[c] These pots received an abnormally high percentage of P_2O_5.

In connection with the study of urephos, pots were included to test the effect of calcium sulphate on plant growth. This material behaved as an inert material on these soils, even with comparatively high applications. This study was included because in the manufacture of a material such as urephos, where cyanamid is treated with sulphuric acid in excess, about 60 to 65 per cent of the fertilizer produced is calcium sulphate.

The results with dicyanodiamide show that it is quite injurious to both beans and wheat and not merely inert. Its toxic effects were much more pronounced on crops grown on sandy soil than on clayey soil, as is almost invariably the case with any injurious substance. Even with the lightest application, the bean leaves turned yellow on the edges and the tips of the wheat blades were burned. With the heavy application, growth was far below normal and the lower bean leaves dropped off. (See Pl. 1, C.)

AVAILABILITY STUDIES WITH WHEAT

A second series of experiments similar to those discussed above was conducted during the spring of 1922, using Norfolk sandy loam and Chester loam. The soils were not from the same lots as previously used, but were collected in the same general localities. Wheat was grown in all of the pots. The experiment was terminated six weeks after planting, earlier than intended because of a severe attack of mildew. The relative green weights of the wheat are reported in Table II.

The wheat data show no very marked differences in the case of the Norfolk sandy loam between sodium nitrate, calcium nitrate, and ammonium sulphate at the two rates of application. The slight differences are within experimental error. Cyanamid, used alone, was much poorer than either of these, but the different combinations with calcium nitrate were all in a class comparable with calcium nitrate alone, or with the two fertilizers used as standards for comparison. Replacing one-fourth of the cyanamid with calcium nitrate furnished a very satisfactory mixture, and where the two materials were used in equal parts the results were even better. Guanylurea sulphate was less satisfactory as a nitrogen carrier than any of the other materials, but did produce some increases, being about one-half as good as sodium nitrate at the largest rate of application and only slightly better than the control at the smaller rate.

The increases in the green weight of wheat produced by the fertilizers on the Chester loam were much smaller with all of the treatments than on the Norfolk sandy loam. In general, however, the results already noted in the case of the lighter soil were also obtained on the Chester loam with the one exception, namely, that the mixtures of cyanamid and calcium nitrate were no better than the cyanamid alone, at the largest rate. It is difficult to explain this result, considering that the nitrogen applications were rather small for greenhouse work and certainly not sufficient to produce any injury on this heavier type of soil.

The observations during growth agreed very well with the final green weights Cyanamid was somewhat slower to act than ammonium sulphate and the two nitrates, but the mixture of cyanamid and calcium nitrate showed quick responses. Guanylurea sulphate produced no toxic effects, but merely failed to increase the growth to any marked extent.

The residual effects of the cyanamid applications on the two soils were negligible, the differences being within experimental error. The same was true of sodium nitrate at the two rates of application on the sandy soil, but on the loam there was a marked increase in yield over the control pots. Guanylurea sulphate increased the yield about 9 to 17 per cent on the sandy soil and 23 to 28 per cent on the Chester loam. These increases were much greater than with either

cyanamid or sodium nitrate, indicating that the material is slowly made available. This may explain the good results [4] previously reported, which were obtained with urephos on winter grain crops. In this case the fertilizer was applied in the fall and not used to any great extent by the plants until the following spring and early summer.

TABLE II.—*Summary showing relative green weights of wheat*

Source of nitrogen	Norfolk sandy loam		Chester loam	
	4-8-4 ratio	8-8-4 ratio	4-8-4 ratio	8-8-4 ratio
No nitrogen	100	100	100	100
No fertilizer	92	92	76	76
Sodium nitrate	216	309	137	158
Calcium nitrate	224	290	131	157
Ammonium sulphate	236	303	139	157
Cyanamid	175	234	125	135
Cyanamid 75 per cent, calcium nitrate 25 per cent	229	283	130	138
Cyanamid 50 per cent, calcium nitrate 50 per cent	240	303	128	128
Cyanamid 25 per cent, calcium nitrate 75 per cent	221	290	134	122
Guanylurea sulphate	117	200	110	128

SUMMARY

The greenhouse experiments reported here, using Norfolk sandy loam and Chester loam soils, are too limited in extent to justify general conclusions, but do serve as good indications of the relative fertilizer values or toxicity for wheat and beans, of the materials studied. These indications may be summarized as follows:

The green weights showed no marked differences between sodium nitrate, ammonium sulphate, urea, ammonium nitrate, calcium nitrate, and ammoniated superphosphate. In the first experiment cyanamid also gave yields corresponding to ammonium sulphate used as a standard for comparison, but in a later experiment with wheat it was less satisfactory. This discrepancy in the results with cyanamid used under controlled conditions in the greenhouse merely verifies similar or more marked variations noted in the field.

Urephos was not so satisfactory a nitrogen carrier as the materials mentioned in the group above. The fact that from 30 to 35 per cent of its nitrogen is in the form of guanylurea is undoubtedly the explanation for the poorer showing. Although the results with the light and medium applications were rather good, the yields at the largest rate were considerably poorer.

Guanylurea sulphate is not a suitable nitrogen carrier. In some instances it produced fair increases in growth, while in others it either seemed to be inert or actually retarded plant growth to a considerable extent. There were some indications that the material is slowly made available and might be of use to a slow-growing crop, but further experimentation will be necessary to establish this point.

Dicyanodiamide injured the growth of wheat, causing a burning of the tips of the wheat blades and a retarding of growth. The injury was even more marked on beans, the leaves turning yellow even with the lightest application. With the heavy application, growth was very weak and the lower bean leaves dropped off. As is usually the case, the toxic effects were most in evidence on the lighter soil.

[4] ALLISON, F. E., BRAHAM, J. M., and MCMURTREY, J. E. FIELD EXPERIMENTS WITH ATMOSPHERIC NITROGEN FERTILIZERS. U. S. Dept. Agr. Bul. 1180, 44 p., illus. 1924.

Plate 1

A.—Growth of beans on a Norfolk sandy loam soil, receiving heavy applications of various nitrogen fertilizers. Acid phosphate and potassium sulphate were added to each pot, except the one containing cyanamid, to which calcined phosphate and potassium sulphate were added.

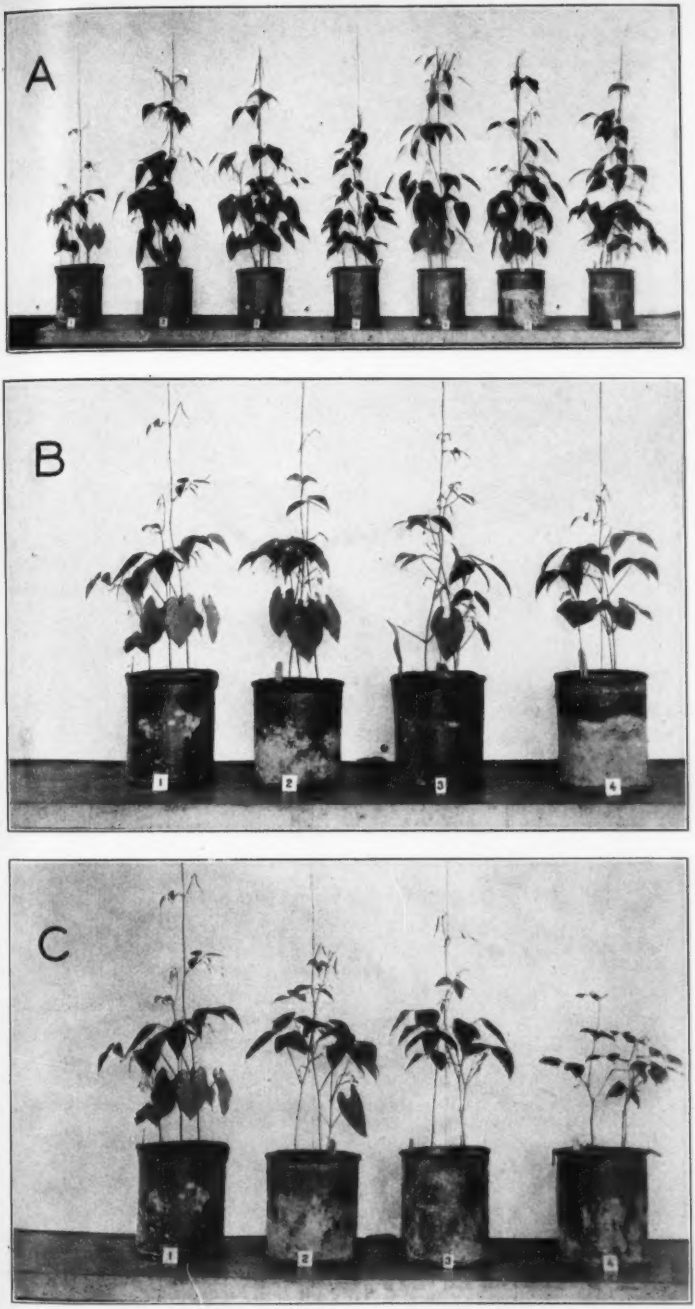
No. 1—No nitrogen; No. 2—ammonium sulphate; No. 3—urea; No. 4—urephos (Chester loam soil); No. 5—ammonium nitrate; No. 6—ammoniated superphosphate; No. 7—cyanamid.

B.—Growth of beans on Norfolk sandy loam, receiving guanylurea sulphate. Acid phosphate and potassium sulphate were added to each pot.

No. 1—No nitrogen; No. 2—small application of guanylurea sulphate; No. 3—medium application of guanylurea sulphate; No. 4—heavy application of guanylurea sulphate.

C.—Growth of beans on Norfolk sandy loam, receiving dicyanodiamide. Acid phosphate and potassium sulphate were added to each pot.

No. 1—No nitrogen; No. 2—small application of dicyanodiamide; No. 3—medium application of dicyanodiamide; No. 4—heavy application of dicyanodiamide.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